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THE COVER: R. R. Anderson (foreground), V. Krueger (above) and R. F. Morra (right) testing preliminary circuitry of the "Recorded Carrier" System. See opposite page.

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To avoid "traffic jams" in the flow of information between computers and business machines in remote locations, Bell Laboratories is actively planning and developing techniques for high-speed transmission of data. The goal is to deliver data so rapidly that transmission lines are used at near-maximum efficiency. Newly developed equipment has a transmission speed of 800 words per minute in teletypewriter code (600 bits per second) and uses magnetic tape for recording data messages. The tape is speeded up for transmission over voice channels.

"Recorded Carrier" System for High-Speed Data Transmission

R. M. GRYB *Special Systems Engineering II*

With the increasing emphasis on the use of data-processing systems, there is a rapidly growing need to transmit data at higher speed. And, because of the extensiveness of the telephone network, it is the most logical facility to meet the objective of high speed and low cost for the largest number of users. Considerable effort is therefore being placed on data-transmission facilities to meet the future needs of high-speed and high-accuracy transmission between fully automatic systems with little or no human intervention.

At the present time, most data to be transmitted originates from manually operated electric typewriters, teletypewriters, calculating machines or cash registers, and is produced at relatively slow speeds. The 60, 75, and 100 words-per-minute teletypewriter services offered today can in many cases adequately satisfy data transmission needs. Nevertheless, with more and more data being produced, customers may find themselves running short of traffic capacity. The need for a method of accepting this manually produced data in its most common form – namely from keyboards and perforated tape or cards – and of transmitting the data at higher speeds stimulated work on what has tentatively been named the "Recorded Carrier System."

There are in existence today many data-processing systems that use perforated paper tapes and cards to store information. The machinery which actually processes the data is designed to accept the information in this form. One of the advantages of the new system is that the data for these processing systems can be transmitted at a speed eight times the present speed without changes in the data-producing or data-processing equipment.

For example, a company having several branch offices may have a system in which all of the sales orders and shipping instructions are typed on a special form. At the same time, a perforated paper tape is made by either the typewriter or a teletypewriter. With present facilities, the paper tape might then be fed into telegraph equipment, which

is generally limited to transmission at one hundred words per minute in teletypewriter code for transmission to the main office.

With the Recorded Carrier System, the information on the paper tape is transferred onto a magnetic tape, perhaps while the typist is busy on the next order. Then, later in the day, when a large number of orders have been recorded, the data stored on magnetic tape can be sent to the main office at eight hundred words per minute. At the main office, an identical paper tape can be produced. Moreover, the data may be sent over a telephone channel which is probably already available for voice traffic, thus eliminating the need for a special telegraph service.

The Recorded Carrier System requires a modulator-demodulator circuit for transmitting and receiving signals over telephone lines. The 43A1 FM carrier telegraph terminal is used for this purpose, since it is designed to operate with existing data machines and is currently manufactured in substantial quantity. A magnetic tape recorder is used at the sending end to record the FM signals and obtain higher speeds. This is accomplished by recording the signals when the tape is moving at slow speed and by playing them back when the tape is moving at a higher speed. The process accomplishes two functions: (1) it increases the speed of transmission of the coded data or "baseband" signals, and (2) it also produces FM signals with a frequency shift suitable for transmitting the data at this speed. The tape recorder actually records the FM carrier frequency instead of the original dc signals; this is why the system is termed "Recorded Carrier."

Although the most likely application of the Recorded Carrier System is with standard teletypewriter equipment, the system can accept any type of serialized binary code at any speed up to 75 bits per second. (A "bit" or binary digit is a quantity of information resulting from a choice between two possibilities – for example, between a 0 and 1, or between the "on" and "off" conditions of a switch.) For descriptive purposes, teletypewriter equipment is shown in Figure 1 as an illustration of a source and use for the dc signals. For this illustration, assume that a paper tape has been made and that it is desired to send the message recorded on the paper tape. Information on the paper tape is in parallel form (each item being a row of holes across the width of the tape), and the transmitter "distributor" converts this information to a serialized form (one unit of information after another in time sequence). Conversion takes place at a typical rate of 100 words per minute (75 bits per second). The "reader" in the equipment thus has an output consisting of serialized dc pulses which cause the 43A1 frequency-shift modulator to swing plus or minus 35 cycles about a 1,615 cps carrier frequency. Next, this 1,615 plus or minus 35 cps output is modulated with a fixed frequency of 1,800 cps, which by subtraction (1,800-1,615) yields a lower-sideband output of 185 plus or minus 35 cps. The upper sideband resulting from the addition of the two frequencies is removed with a low-pass filter.

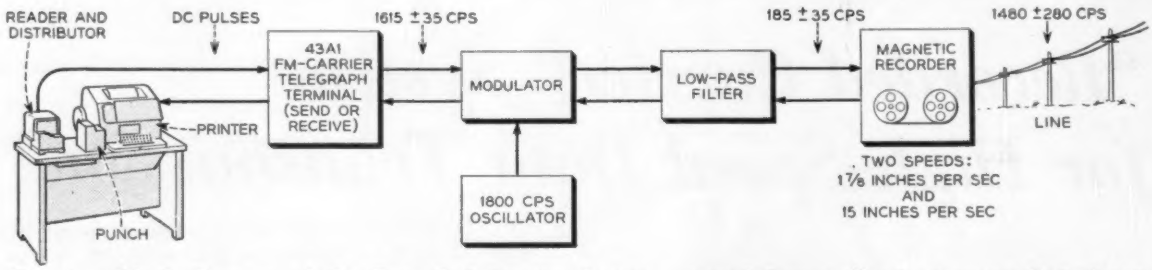


Fig. 1 — Block diagram of the Recorded Carrier System — speeded-up magnetic tapes result in faster transmission of digital text or data codes over telephone voice channels.

The frequency-modulated 185 plus or minus 35 cps signal from the filter is then recorded on the magnetic tape at a speed of about 1⅞ inches of tape per second, and is played over the telephone voice channel about eight times as fast (600 bits per second). Therefore, the 185 plus or minus 35 cps multiplied by eight becomes an FM transmitting signal of 1,480 plus or minus 280 cps.

To avoid rewinding the magnetic tape before transmission, the information is sent over the line backwards – that is, the last signal recorded becomes the first on the line. However, when receiving, another reversal takes place so that the information is sent into a teletypewriter or other

receiving machine in the proper order. When the high-speed signal on the line is received, it is recorded on the receiving magnetic tape at approximately 15 inches per second and played back at about 1⅞ inches per second. The same circuits are used to convert the 185 plus or minus 35 cps signal from the recorder to 1,615 plus or minus 35 cycles, the proper input frequency for the 43A1 terminal. The 43A1 terminal then converts the frequency-shift signals to dc signals. The magnetic-tape transcriber and associated equipment is therefore a two-way device. It can only be used one way at a time, however.

In determining the amount of speed-up, the controlling factor was what could readily be obtained from a recorder which had two-speed capability and good speed control without excessive cost. It was desirable to avoid requirements which demand a high-priced scientific type of magnetic tape recorder or a recorder of entirely new design. It was found that an 8 to 1 ratio can be readily provided without going to either of these extremes, although probably a somewhat higher ratio could be used without exceeding the limitations of available bandwidth.

Even though the Recorded Carrier System does not include error-control features in the process of transmission, it is a relatively flexible system and has the advantage that it will work with any existing digital text or data equipment regardless of the code used, such as 5, 6, 7, or 8 elements per character. Any redundancy in the code for error-checking purposes will be transmitted over the line and will serve to detect transmission errors. No errors will be detected at the time of transmission but will be discovered when the tape is played back at slow speed at the terminating end.

The magnetic tape recorder is a two-track machine — one track is used for recording outgoing data messages (off-line operation), and the other track is used for recording incoming messages (on-line operation). It is therefore possible to have both outgoing and incoming messages recorded on the tape without interference. The recorder uses a 950-ft reel of ¼-inch tape, which has a storage capacity of an hour and 36 minutes of recording off-line at 75 bits per second, or 12 minutes of on-line recording at 600 bits per second. This amounts to about 400,000 bits each of incoming and outgoing data, or a total of about 800,000 bits of both. The tape can be positioned manually to locate messages so that they can later be identified and replayed if desirable, by means of noting the position of a revolution counter associated with it.

Fig. 2 — R. R. Anderson (left) and G. T. Cindric observing distortion characteristics.

To use this flexibility with relatively simple operation so that an attendant does not have to remember which track to use or worry about destroying data by operating errors, and to make it possible for the attendant to perform other duties while the recording is in process, automatic features are provided. Preceding and following each data message, there are blank spaces of tape of lengths which insure that no carrier signals appear for 40 seconds at the slow speed, or for 5 seconds at the high speed. These blank spaces of tape permit an end-of-message detector to stop the recorder and disconnect the telephone voice channel or sound an alarm. In addition, a blank space of tape of a length which lasts 5 seconds at the slow speed is provided each time the off-line recording is stopped and started again. This permits an attendant to interrupt the recording for any reason, possibly to receive an incoming call, and later to continue the recording without introducing errors due to transients from starting and stopping the tape. This feature also permits an attendant, who has interrupted a message during an off-line recording, to play it back at slow speed for checking purposes. The machine will automatically indicate where the attendant left off. The blank period of 5 seconds becomes a fraction of a second at the high speed and does not operate the end-of-mes-

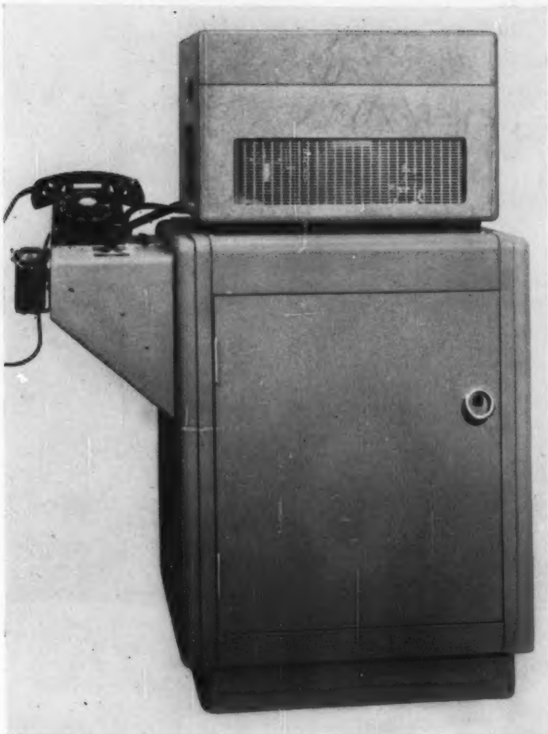


Fig. 3 — Later version of the Recorded Carrier System equipment with modified control panel.

sage detector. Logic and timing are provided in this control circuitry to recognize the operation of push buttons and to determine the action that should be taken.

Figure 2 shows a preliminary model of the Recorded Carrier System equipment which was used in an evaluation trial. Experimental commercial models for customer trials are of similar physical dimensions, but the cabinet for the electronic equipment is somewhat altered to facilitate improved equipment layout. A monitoring speaker is provided with an adjustable gain control. This permits the attendant to listen to the data being recorded or played back either on-line or off-line. It is particularly useful on-line for assurance that the data message either is still in progress or has been completed.

Figure 3 is a photograph of a later version of the Recorded Carrier System for customer use, and Figure 4 is a closeup of the control panel mounted on the side of the cabinet. This panel provides a selector switch to permit the attendant to perform the following functions: (1) record a message off-line preparatory to transmitting, (2) transmit a previously recorded message on line, (3) receive an incoming message on line, (4) play back a previously recorded message on line, (3) receive an off-line recording to verify its accuracy or to determine where an interrupted message was left off, and (6) leave the system in an idle position (normal), which provides power to the electronic circuits but not to the motors.

The control panel includes three 2-position keys. One key is for moving the magnetic tape to the left or right to locate messages on the tape; the second key is used to start and end the message when recording off-line; and the third key is used to start the message when playing back off-line or when transmitting on-line. The stop position of the second key is to stop an off-line recording when it is necessary to interrupt in the middle of the recording. In addition, there is a power switch and a key to switch the Recorded Carrier System so that it will record messages from either the paper tape transmitter-distributor or directly from the keyboard of the teletypewriter.

The Recorded Carrier System is intended to be associated with a channel that can be used for either voice or data. Herein lies the greatest ad-

Fig. 4 — Close-up of control panel on side of the Recorded Carrier System cabinet.

vantage of the Recorded Carrier System. Several messages can be recorded on the magnetic tape, and during the slack periods when the customer's line is not busy with voice traffic—such as during the lunch hour or immediately following the normal working hours—a large amount of data can be transmitted in a relatively short time. Because of this combined use of the voice channel, the operating procedure for the Recorded Carrier System depends on voice coordination for preparing to transmit and receive a data message. After the usual introductory conversation, the attendants would agree to transmit data. They would then set the equipment to transmit or receive and would operate the start key. Transmission of the data will start approximately five seconds later. The 5-second delay is due to the blank portion following the recorded message and also makes precise coordination unnecessary.

If the attendants want to converse after the data message has been transmitted, they can agree ahead of time to place the telephone receiver on a special switchhook on the side of the Recorded Carrier System cabinet. When the end of data message is detected, the line is transferred from the Recorded Carrier System to the telephone, and an alarm sounds. When the receiver is removed from the special switchhook, the alarm ceases. If they do not desire to converse after the message, they both can hang up their receivers on the regular telephone switchhooks. Then, when the end of data message is detected, the line is automatically disconnected and a momentary alarm is sounded.

The tape recorder has two motors – one for moving the tape left-to-right at slow speed and one for moving the tape right-to-left at high speed. In the process of recording and transmitting a message at one station, and of receiving and playing it back at the other station, four motors are therefore used to drive the tapes – two motors at each station. Any variation in the speed of tape movement due to the drive mechanism results in distortion of the signal which causes the operation of receiving data-printing or perforating. This distortion results in a lengthening or shortening of the dc pulses. Preliminary tests and trials of the Recorded Carrier System indicate that the tape speed variation can be kept within a range where distortion from this source does not become severe. The carrier frequencies are in the approximate center of a voice channel where distortion due to delay characteristics is small. Therefore, there is still considerable margin for tolerance against additional distortion in transmission resulting from occasional noise.

The Recorded Carrier System is a useful tool for working with existing data-producing equipment. It should provide customers an opportunity to gain experience with higher speed data-transmission systems and should give them a feel of the impact of future data-transmission schemes. Similarly, the Bell System will be able to obtain information regarding performance and customer needs which will be helpful in the planning of other systems.

THE AUTHOR

R. M. Gryb, a native of Mt. Vernon, N. Y., received the B.S. degree in Electrical Engineering in 1946 from the University of Illinois. He joined the New York Telephone Company in that year, and as an engineer in the General Traffic Department was concerned with the design of central office equipment and trunking arrangements. In March, 1951, he transferred to the Laboratories, where he has been concerned with traffic measuring devices, No. 5 crossbar switching equipment, and switching and signaling techniques for naval communications. He is currently working in the field of data transmission for commercial Bell System service. Mr. Gryb is a member of the I.R.E. and the A.I.E.E.

Air-Ground Circuit for Airlines

N. MONK *Systems Engineering*

Besides the prime responsibility for millions of telephones, the Bell System is called upon to furnish a wide variety of other types of communication services. Some time ago the American Telephone and Telegraph Co. was asked to provide improved ground facilities for communication systems along several main airline routes in the continental United States. To assist in engineering such systems, theoretical studies and tests of simulated equipment were conducted at Bell Laboratories.

At the present time, airline personnel communicate with aircraft by voice or teletypewriter over wire lines extending to radio stations along the airways. The messages are transmitted to and received from the aircraft in flight at the radio stations by voice communication over a radio channel. Hence, they must be relayed by radio operators at the radio stations. This method of communication is quite workable, but it would obviously be better for airline people to communicate directly with pilots. Because air traffic is increasing, and because of the consequent increase in complexity of handling such traffic, the Bell System was requested to provide ground facilities for a direct service along a number of important airways.

The first impression might be that the establishment of circuits of this type is relatively simple: merely connect all the radio stations along a route with telephone lines, and let the airline personnel talk to the pilot over the combined telephone-radio circuit. Such a circuit is illustrated in Figure 1. The idea here is to link all the radio stations together by a four-wire system – that is, one pair of wires or channel for transmitting and a second pair or channel for receiving. Arrangements are incorporated for switching the radio equipment between the transmitting and receiving conditions (as indicated by the dashed lines in Figure 1), and airline personnel at the two ends of the route may thus call any aircraft in flight. The arrangement is in effect one long party line by which all aircraft flying over the route share communication time on a single radio frequency.

This communication setup, however, is more complex than it might seem. Let us discuss for a moment some of the factors that must be considered. Frequencies in the band from 122 to 132 megacycles have been assigned by the FCC for commercial airline air-ground communication. Radio equipment operating in this frequency band is carried on all commercial planes for this and other communication purposes. The equipment employs amplitude modulation. Since this equipment was to be used, the air-ground circuit had to employ this type of modulation. Also, it had to operate in the above frequency band.

Another requirement is that ground radio stations must be spaced relatively close together; otherwise low-flying aircraft would encounter "blind spots" between stations. On the other hand, high-flying aircraft, at about 20,000 feet, receive signals from several stations simultaneously. Since no two

radio transmitters can ever be maintained absolutely on the same frequency, and because of the Doppler effect, radio-frequency carrier energies from two or more ground stations mix together and produce "beats" in the aircraft receiver. The frequencies of these beats may fall within the voice-frequency range and thus produce audible tones that obscure or even drown out voice communication from the ground. When transmission is received from only two or three sources, these heterodyne beats can be eliminated by operating the ground stations at slightly different carrier frequencies – close enough together to be accepted by the receivers when tuned to the same channel, but far enough apart that their difference or beat frequencies fall outside the received voice band. This "frequency-offset" method of operation has been known for some time and has been proven by flight tests. However, with planes now flying at altitudes of 20,000 feet or higher, it is possible to receive from a considerable number of ground stations simultaneously. Thus, the many beats resulting from the intermodulation of the various carrier frequencies cannot all be made to fall above the voice range by the frequency-offset method. This is because the limited pass-band of the plane receivers restricts the freedom with which the ground station frequencies may be shifted. That is, the narrow bandwidth does not permit the use of very many widely spaced offset frequencies.

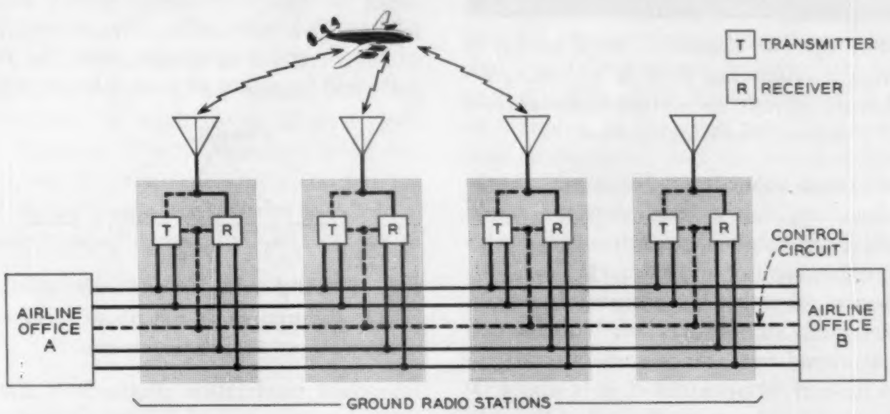


Fig. 1 — Air-ground communication circuit using telephone lines to connect radio equipment located at stations along an airway.

A communication circuit like that indicated in Figure 1 is subject also to another type of distortion which in this case occurs in both directions of transmission. Signals transmitted from the airlines office, for example, will suffer different time delays in reaching the various radio stations, because of the different lengths of wire line encountered. A delay distortion of the signal received in the plane results; this is similar to the "echo" that has been noted in transmission over long-distance voice-frequency telephone circuits.

These and other problems raised the question as to whether a system of the type indicated in Figure 1 involving more than three ground stations was in fact feasible, and if so, what had to be done to minimize the effects of heterodyne beats and delay distortion. The answer was approached initially by a theoretical analysis and later by actual tests of simulated equipment.

As a first step, an analysis was made of the characteristics of the various AM detector circuits used in radio receivers. Such detectors convert the modulated radio-frequency signal into an audio voltage, and may be categorized as either "fast" or "slow," depending upon the time constant of the detector circuit. That is, a detector may respond rapidly or slowly to a change in strength of the incoming signal. Performance in producing beat notes from two carrier frequencies was found to be about equal in the two types, but where more than two carrier frequencies were involved the "fast" detector was appreciably superior in minimizing beats due to fourth and higher even orders of modulation.* On the other hand, the slow detector was found to exhibit somewhat better performance in the presence of delay distortion. It was found, however, that delay distortion should not be serious if the difference in the transmission delay between two signals as received by the air-

* As used here, a second order product is one which results from modulation of two frequencies; a fourth order product results from four frequencies; etc.

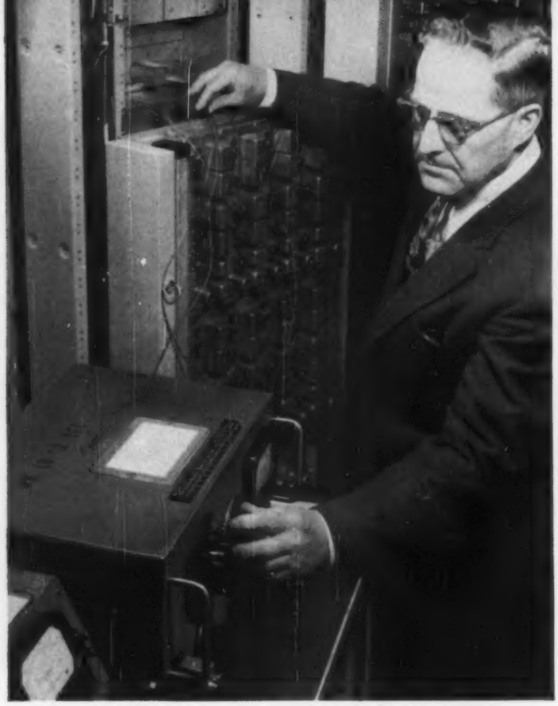


Fig. 2 — Group of N-terminals; J. R. Wenrich of the Long Lines Engineering Staff is adjusting resistor in channel circuit to simulate signal-level as received by aircraft radio equipment.

craft did not exceed about ten milliseconds. It was concluded, therefore, that a "fast" detector would be preferable. Fortunately, presently used equipment employs this type of detector.

The question of offsetting the carrier frequencies at the various radio stations (called "subchanneling") was considered next. Since some aircraft radio receivers have rf bandwidths of only about 30 kc, it was assumed for the study that all of the subchannel frequencies must fall within this bandwidth. It was also assumed that stations should be at least 6 kilocycles apart. This frequency difference was chosen for two reasons. First, a beat note of 6 kc falls outside of the normal voice band and could, if necessary, be substantially eliminated by a low pass filter. Second, with this frequency difference no serious overlapping of sidebands would occur. Thus, there is room in a nominal 30 kc band for only six frequencies spaced 6 kc apart; if we call the mid-band frequency F, these six frequencies are F + 15 kc, F + 9 kc, F + 3 kc, F —3 kc, F — 9 kc, and F — 15 kc.

A subchanneling arrangement using these frequencies is indicated in Figure 3. The radio stations are here assumed to be about 80 miles apart. Ordinarily, the strongest signals would be received in the plane from the nearest station. To limit interference as much as possible, it was concluded that the six frequencies should be assigned in such a manner that strong signals from any two or three adjacent stations could not produce a second or fourth order beat note in the voice band as a result of the mixing of the several frequencies. The method shown in Figure 3 is that the frequencies are irregularly assigned so that the frequency of one station is always 12 kc away from the station on one side and 18 kc away from the station on the other side. Thus, station C is 12 kc away from station B and 18 kc away from station D. With these frequency allocations, it is unlikely that an aircraft will receive more than three or four signals at any given time strong enough to contribute materially to beat-note interference. This is true even though the aircraft is above 20,000 feet, where six or even more stations may be within line-of-sight.

The subchanneling system shown in Figure 3 theoretically eliminates the production of beat notes falling between zero and 6 kc. That is, by adding and subtracting the various combinations of the several frequencies along the route, the results will be either at least 6 kc or zero. Hence, all

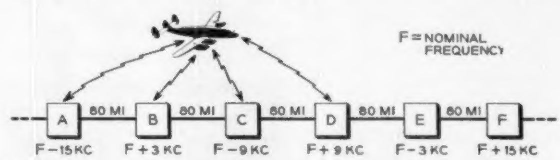


Fig. 3 — Different frequencies along an airway route; differences do not affect receiver tuning but decrease beat-note interference.

important modulation products of the carrier frequencies must be either zero or multiples of 6 kc.

This theoretical limitation of the potentially troublesome low frequency beats occurs, however, only if the frequencies of the ground stations are maintained exactly. Accuracy of present transmitters is about plus or minus 0.001 per cent, which means that a transmitter operating at 125 megacycles could be 1,250 cycles off frequency. This error can result in second order beats as low as 2,500 cycles, fourth order beats from 0 to 5,000 cycles, sixth order beats from 0 to 7,500 cycles, etc. To keep such beats either above approximately 6 kc or in the lower end of the voice band (below about 300-400 cycles), it was concluded that the ground radio transmitters must be held to a frequency stability of plus or minus 0.0001 per cent (125 cycles). With this arrangement, second order beats will be held above 5,750 cycles and the higher order beats will, even including a suitable allowance for Doppler effect, normally fall within the range 0 to 300 or 400 cycles. These beats may be heard

but they do not seriously affect intelligibility unless they are of high amplitude and are of the order of 50 cycles or less in frequency. In this case, modulation of the speech at a syllabic rate causes severe loss of intelligibility. In the plan of Figure 3, the amplitude of these very low-frequency beats is low and distortion is minimized.

To test this theoretical analysis with actual airplanes in flight would have been exorbitantly expensive. It was believed, however, that type-N carrier telephone equipment could be adapted for observation of beat note interference and the effect of delay. Type-N carrier* transmits up to 12 telephone message channels by amplitude modulation of carrier frequencies spaced 8 kc apart. By modifying a transmitting terminal of type-N equipment, and by using at the receiving end a detector circuit similar to that employed in aircraft radio receivers, various circuit conditions could be simulated. Accordingly, tests were set up with the aid of the Long Lines Department of the A.T.&T. Co.

As illustrated in Figure 4, the arrangement for these tests involved the modification of six type-N transmitting channels. The compandors were removed and a variable resistance for changing the energy level of the transmitted carrier was added to each transmitting channel (left part of the illustration). Also, a variable oscillator (top left) for changing the frequency of the transmitted carrier was substituted for the regular oscillator of one channel, and a network for introducing time delay (bottom left) was inserted in another channel. All channel frequencies passed over an artificial line into a single receiving circuit, indicated in the right part of the illustration. A detector circuit similar to the type used in aircraft receivers was incorporated, and the detected signal was amplified and fed into a loudspeaker. Speech signals from a telephone or from tape recordings could thus be heard through the loudspeaker by various observers. The principal elements of the transmission system were thus simulated except for the

Fig. 5 — W. R. Young of the Laboratories with special aircraft-type detector used in the simulation tests of air-ground communication system.

* RECORD, *September*, 1953, *page* 347; *November*, 1953, *page* 452.

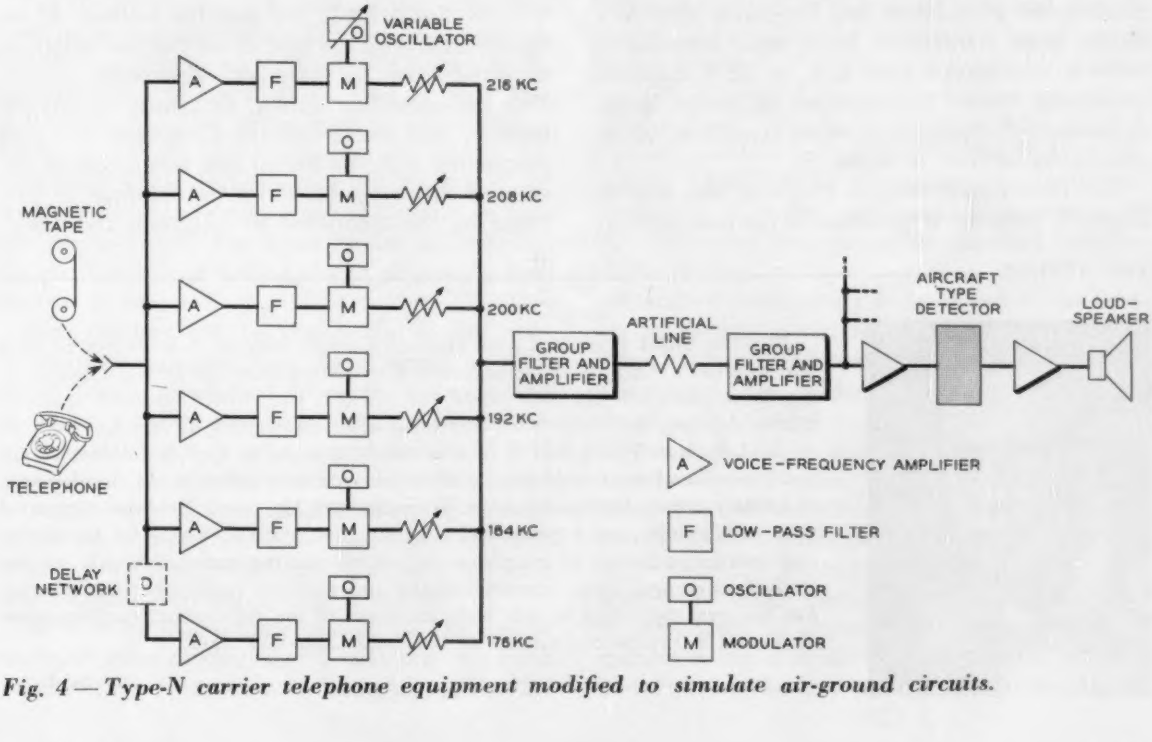


Fig. 4 — Type-N carrier telephone equipment modified to simulate air-ground circuits.

ground-airplane path and a noise limiter which may be used between the detector and the audio amplifier in the receiver. Subsequent to the tests described below, it was found that precautions must be taken to avoid undesirable effects due to the noise limiter.

In Figure 4 the six transmitting channels represent six ground radio stations; the different signal strengths as received by the aircraft were simulated by adjusting the variable resistances in the separate channels. The channels here are normally 8 kc apart instead of the intended 6 kc of the actual radio transmitters, but the frequency of the one channel was varied to test the effect of different separations. Different time delays were also introduced. Observers listening to the loudspeaker output could easily detect good and bad conditions of beat and time-delay interference.

Frequency separations of 3, 5, 6, 8, and 10 kc between two channels were tested, and the efficacy of different filters in reducing interference was observed. Also observed were the effects of zero, 1, 2, 4 and 8 milliseconds of time delay. (This confirmed previous tests which indicated that delays up to about 10 milliseconds could be tolerated.) Then, using three channels – the channel with the variable oscillator and the two channels adjacent to it – tests were made involving frequency offsets of — 8, 0 and + 8 kc, and of — 8, 0 and + 16 kc. These tests illustrated the effects of second- and fourth-order modulation and frequency drift in a station radio transmitter. Tests made with simultaneous transmission over 4, 5, or all 6 channels, employing various combinations of carrier levels, demonstrated typical and worst conditions of reception by aircraft in flight.

The tests confirmed that a system like that in Figure 1, with the frequencies of the base stations suitably offset, was practicable. They demonstrated that the undesirable effects caused by multiple transmission will not interfere seriously with intelligibility, even though these effects are unavoidable and at times annoying. Further, the theoretical analysis and the simulation tests indicated several guides to be followed in engineering such circuits: (1) a "fast" detector in the aircraft receiver is significantly better in reducing beats due to fourth and higher orders of modulation; (2) delay difference is not critical up to about 10 milliseconds, although delays of about 2 milliseconds produce more distortion than shorter or longer delays; (3) to limit the effect of beat notes and permit the use of inexpensive filters, if desired, frequency-offset should not be less than 6 kc; (4) frequency stability of the ground radio transmitters should be held to 0.0001 per cent; (5) strong signals likely to be received simultaneously should be at different frequencies; (6) geographically adjacent radio stations should be separated by more than the 6 kc minimum frequency difference; (7) groups of three geographically adjacent stations should not be spaced uniformly in frequency; and (8) at least five, and preferably six separate sub-carrier frequencies should be stacked within the RF channel of any such system.

At the conclusion of the Laboratories study, the more significant tests and a number of typical and worst conditions were demonstrated to representatives of the A.T.&T. Co. and the airlines, to acquaint them with the type of service that might be expected from the proposed air-ground circuits. This demonstration showed that such circuits are feasible, and the Telephone Companies are now proceeding with the design and installation of circuits of this type, based on the information provided by the theoretical investigation and tests.

THE AUTHOR

NEWTON MONK graduated from Harvard College with the A.B. degree in 1920 and received the B.S. in Communication Engineering from the Harvard Engineering School in 1922. He then joined the A.T.&T. Co., where his work included carrier developments which he continued after transferring to the Laboratories in 1934. Prior to World War II he was chiefly engaged in applying carrier equipment to railroad communications systems and later was active in the development of military communications systems. Since the war, Mr. Monk has been concerned with mobile radio, and a group under his direction was responsible for the design and initial application of telephone service for moving trains. Recently he has studied air-ground radio communications and personal radio signaling systems. For the past two years he has been chairman of the Administrative Committee of the I.R.E. Professional Group on Vehicular Communications.

Conductive and Resistive Coatings

R. J. PHAIR *Chemical Research*

Frequently an electronic device or component will require a thin conducting layer of a specified size, shape and resistance to serve as an electrical shield or to perform an actual circuit function. Of the many ways of formulating and applying such conductive layers, one which shows great promise is the use of resins or lacquers pigmented with metals or carbon. These can be applied like paint to give thin resistive films in complex patterns or may also be used advantageously to cover irregular surfaces.

The usual purpose of a paint coating is to decorate or protect the surface to which it is applied, but paint or organic coatings actually have a much broader range of applications. One of their less well-known uses, for example, is to conduct electricity. Ordinarily, paint pigments are chosen for their color or weather-resistant quality, but if we properly disperse certain types of metallic or carbon pigments into a resinous binder or "vehicle," the result will be a coating that is electrically conductive in nature.

Such coatings can be very useful in the communications industry. They have served as electrical shields on electron tubes, for instance, and on radar housings and plastic-encapsulated components. Among their other experimental and field applications, conductive coatings have been used as resistor terminations, in printed-wiring circuits, on flexible waveguides, on loss-producing elements in microwave attenuators, and in many other areas where a thin conductive film is required.

As in other coatings, the vehicle used to contain the conductive pigment may be any one of a great variety of air-drying or oven-drying substances. Selecting the proper vehicle is an important consideration in any particular application, involving as it does questions of the manner in which the coating is to be applied and of its effect on the underlying surface. This, however, is in some ways a separate problem not pertinent to the present discussion, which will be mainly concerned with the conductive pigments employed. Pigmentation is the chief factor determining the electrical behavior of the coating.

Electrical conductivity is developed in the coating by particle-to-particle contact, as indicated in Figure 1. In this photomicrograph, it can be seen that particles are dispersed uniformly throughout the coating to result in a multiplicity of paths in all directions. Thus, electrical conductivity of the coating depends upon the concentration of particles, their conductivity, and the resistances of the particle-to-particle contacts. The over-all resistance of a conductive coating is described as a certain number of ohms "per square." The factors mentioned above as determining conductivity have nothing to do with the *size* of the area covered. In its circuit, the coating will exhibit a resistance

determined by its *shape* — that is, by the proportionate dimensions of the rectangular, square, or irregular area that it covers. In other words, with a square area and a constant thickness of film, the resistance from one side to the opposite is constant, regardless of the size of the square.

For maximum conductivity, one chooses a metallic pigment that does not oxidize or combine chemically with the vehicle or the atmosphere, or a pigment whose reaction products are also conductive. Such metallic pigments as aluminum and copper are therefore eliminated, since these form non-conductive surface layers. Of the suitable pigments, finely divided silver is the most frequently used, though special cases may require gold or nickel. The silver most frequently employed is in the form of high purity, flake-like particles averaging about 0.1 micron thick, 10-20 microns wide, and up to 40 microns long. (One micron equals one-thousandth of a mm.) With silver-pigmented coatings, resistance levels as low as about 0.1 ohm per square are attainable.

For higher levels of resistance — in the range of 40 to 1,000 ohms per square — graphite is used. The particles are obtained from Ceylon graphite refined to a purity of 97-98 per cent, and are also in flake form with an average size of 2.5 microns. Films of still higher resistance levels — from 1,000 ohms up to the megohms region — are obtained by pigmenting with carbon black or with combinations of carbon black and graphite. The carbon black materials include the acetylene and channel blacks obtained from the incomplete combustion of natural gas and oil. These materials are finer in particle size; the particles average 0.05 micron and their conductivity varies according to the amount of graphite form of carbon present in the carbon black.

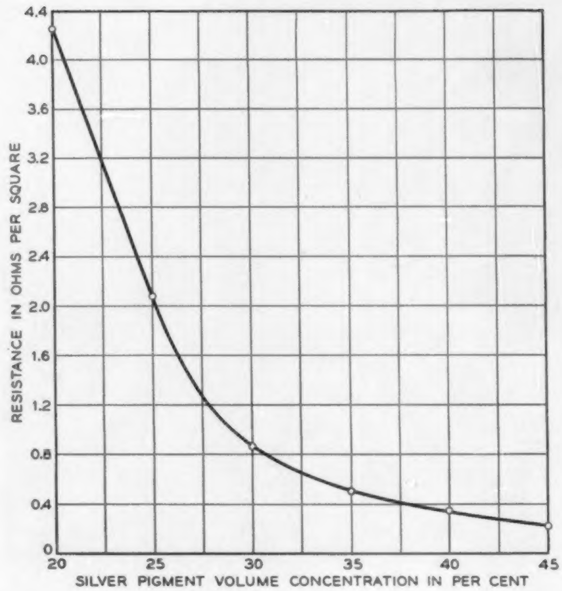


Fig. 2 — Resistance of silver-pigmented film versus concentration of silver; thickness is constant.

Characteristics for a typical conductive coating are shown in Figures 2 and 4. The film used for the data of these curves was an acrylic ester polymer pigmented with silver. This coating will air-dry and is suitable for use on many thermoplastic compounds. The electrical behavior of such films, however, is largely independent of the vehicle, so that Figures 2 and 4 are typical of silver in a number of resinous binders.

In Figure 2, resistance in ohms per square is plotted against silver-pigment concentration in per cent of pigment by volume of the dried film. The various concentrations refer to films of equal thickness (0.0003 inch). From this curve, it is seen that there is a rapid lowering in resistance with increasing silver content up to a concentration of about 30-35 per cent. Higher pigmentation results in a small additional lowering of resistance, but considerations of expense and of the preservation of satisfactory film characteristics usually limit the concentration to a maximum of about 40 per cent. Of course, resistance can also be changed by changing the thickness of the film, as shown in Figure 4, which gives values of resistance for various thick-

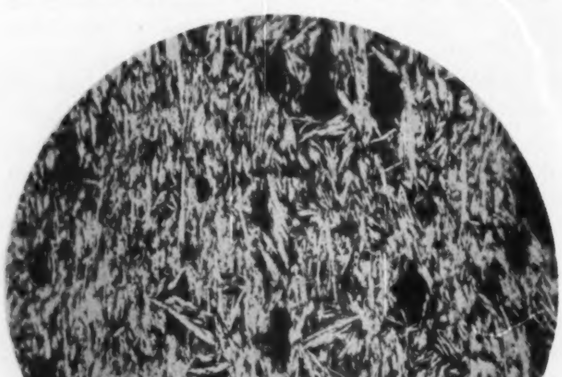


Fig. 1 — Dispersed particles in intimate contact create electrical paths through coating.

nesses of a film containing 30 per cent by volume of silver.

It will be noted that the curve in Figure 4 resembles an hyperbola. In fact, it approximates the hyperbolic function $R = r(l/a)$, where r is a constant and R, l, and a are the resistance, length, and cross-sectional area of a conductor. For resistive films, this expression reduces to $R = r/t$, where R is resistance per square and t is the thickness.

It should also be noticed in Figure 4 that the silver-pigmented coatings approach maximum conductivity at thicknesses of about 6-7 ten-thousandths of an inch. Thus, to achieve minimum resistance, we can use such films at the maximum silver concentration of 40 per cent and obtain a film with a resistance as low as about 0.06 ohm per square. This is about 50 to 60 times the resistance of silver or copper metal of identical dimensions. Further, the copper foil used in printed-wiring circuits is usually about 5 times as thick as such films (approximately 3 thousandths of an inch), which means that by this comparison the resistance of the silver-pigmented coating is 250 to 300 times greater.

The emphasis thus far has been on films that employ silver, but often it is desired to produce a film with a higher specific level of resistance, in which case the material used is graphite. As with the silver-pigmented films, resistance is adjusted by varying concentration and thickness. Figure 5 shows resistance-thickness curves for two concentrations of graphite – 28 per cent of graphite by volume in the upper set of curves and 38 per cent of graphite at the bottom. In each case, the dashed and solid curves illustrate the effect of short-term aging (8-10 days) during which the initial value of resistance drops to a more stable value.

Fig. 3.—The author and R. J. Caroselli (foreground) checking resistance of a film during baking cycle.

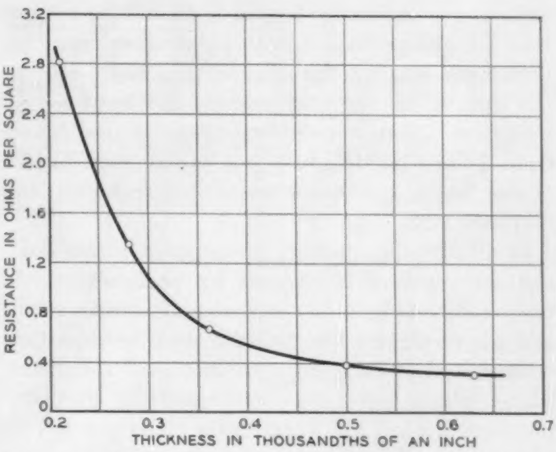


Fig. 4—Resistance versus thickness of film for 30 per cent by volume of silver pigment.

The curves in Figure 5 are also drawn to illustrate another important consideration in designing conductive films. It can be seen that by varying graphite content, the curve can be made to "level out" at any particular value of resistance. This allows more variation in film thickness without a marked change in resistance; as seen in Figure 5, when film thickness approaches 0.001 inch, a 10 per cent variation in thickness has little effect on the resistance value.

Careful control in applying films is nonetheless necessary. An automatic spray machine has been developed for the purpose, and it is necessary to regulate very precisely the air-drying speed and to build up the required thicknesses of films carefully by the application of several layers. With this type of control, the over-all resistance of a film can be held within plus or minus 5 per cent of the nominal value, and variation of resistance over fairly large areas (12 by 2¼ inches) can be held within similar limits. Unless there is absolute necessity for such close tolerances, however, 10 per cent variation in over-all resistance is allowed, although variation over adjacent sections of the area is maintained at plus or minus 5 per cent. These remarks apply not only to the graphite-pigmented coatings of the type described by Figure 5, but also to carbon-black coatings at higher levels of conductive-film resistance.

Typical characteristics for a carbon-pigmented

coating are shown by Figure 6. It will be noticed that a 5 per cent change in pigment volume concentration changes the resistance level by one order and at 15 per cent extends the level to 100 megohms. Thus a complete range of resistances from 1/10th to 10^8 ohms per square may be obtained by proper selection of pigmentation and film thickness.

In all of these coatings, the organic binder holding the pigment is affected by environment. As temperature or humidity increases, the binder swells and the result is a less intimate particle-to-particle contact and consequently an increased resistance. These effects have been measured for graphite-pigmented, air-dried films: 8,000 ohms per square films increased in resistance by about 0.33 per cent for each per cent increase in relative humidity, and 200 ohms per square films similarly exhibited an increase of about 0.25 per cent. The 200 ohms per square graphite films showed about a 0.20 per cent increase in resistance for a temperature rise of one degree F. Vehicles cured by oven-baking can be used to reduce such temperature and humidity sensitivity. Silver-pigmented coatings showed temperature and humidity coefficients of about one-third these values.

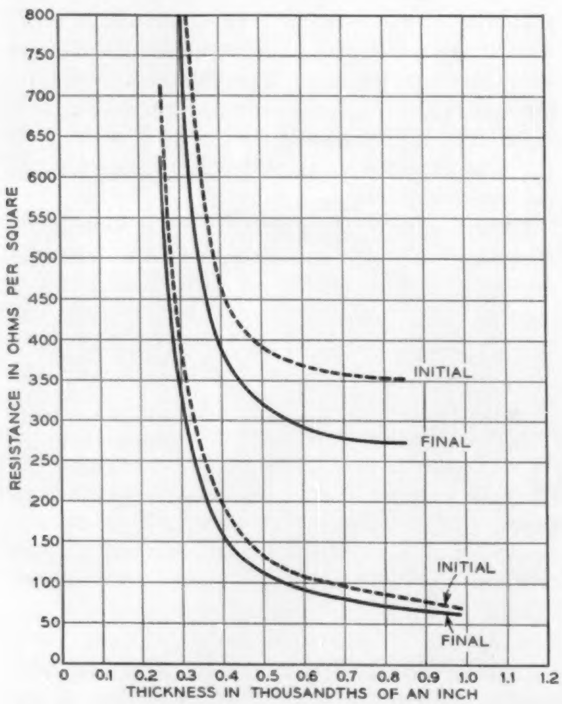


Fig. 5 — Resistance versus thickness of film for two concentrations of graphite; dashed and solid curves show effect of short-term aging.

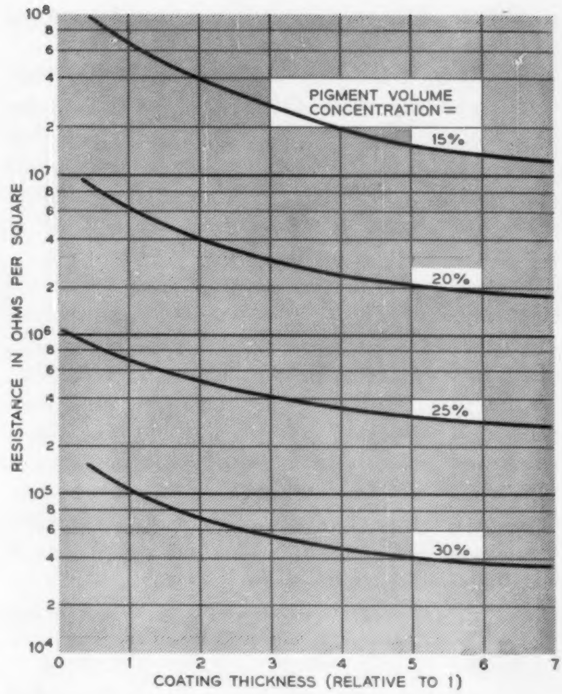


Fig. 6 — Resistance versus film thickness for four concentrations of carbon black in acrylic ester polymer used as the binder.

As mentioned earlier in connection with Figure 5, air-dried films exhibit a short-term aging effect: resistance drops rapidly in the early stages but apparently levels off after about 8-10 days at a value about 25 per cent less than the original. The materials are not stable, however, and if the film is aged at 125°F, resistance continues to decrease gradually over a period of two years. The final value is less than 50 per cent of the original. While this is undesirable, it is difficult to avoid, especially when the film is applied to a temperature-sensitive base material such as oriented polystyrene. This material cannot be heated above 150°F without distortion to the film.

Greater stability is attainable by using binders that are heat-cured at high baking temperatures. One example of this type of film is given here – a resistive coating for which the binder is a silicone resin and which uses 40.5 per cent by volume of graphite as the pigment. This film was developed to provide an electrical loss-producing element for use in the TD-2 and TH microwave radio-relay systems. A vane formed with the ceramic material steatite* is coated with the film, so that when in-

* RECORD, *October*, 1955, *page* 369.

serted into a waveguide, the vane produces the desired loss in the microwave energy.

The prolonged baking and other processing required to achieve stability is illustrated by Figure 7. This curve shows the resistance history during baking of the graphite film over a period of 160 hours. The peak in the curve at 97 hours (point D) results from the application of a clear over-coating at this time. The clear coating is applied for mechanical protection and as a moisture barrier against short-term increases in relative humidity. The temperature and humidity effects on this film are much reduced. Resistance increases only about 0.12 per cent for a one degree F rise in temperature and only about 0.05 per cent for a one per cent rise in relative humidity. Long-term stability is also considerably improved; a 105 ohms per square film aged for five months with periodic increases in temperature up to 300°F drops only one ohm to a final value of 104 ohms per square.

From these descriptions of a few of the many possible types of conductive and resistive coatings, the versatility of such films is readily apparent. They are not substitutes for metals where very low resistance is required, but at higher resistance values they offer many advantages. Where tailoring resistance to specific values may be a complex problem in the mixing, fusing, or alloying of solid materials, the metallic pigmenting of a liquid binder is often a much simpler procedure for certain applications. Temperature, humidity, and aging effects complicate the design of films in some circumstances, but films are nevertheless preferable in many instances because they can be applied over irregular shapes and also can be applied in complex geometric patterns.

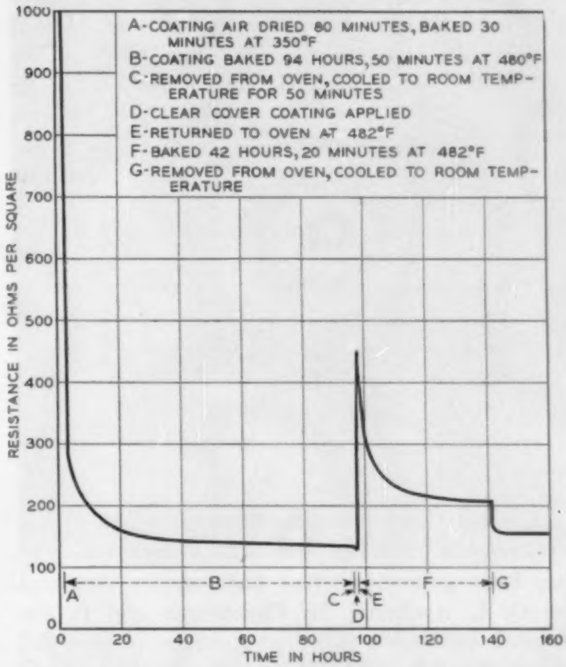


Fig. 7 — Change in resistance of a graphite-pigmented silicone coating during oven baking and application of a clear cover-coating.

THE AUTHOR

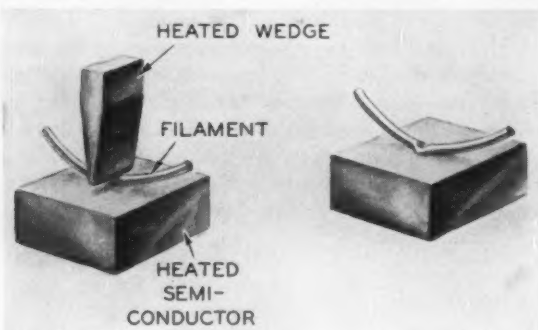
R. J. PHAIR, a native of Hoboken, N. J., received the B.S. degree in Chemical Engineering from the Newark College of Engineering. He joined Bell Laboratories in 1928 and began work on organic finishes in 1938. Since then he has been engaged in the engineering of organic finishes on telephone communication products, including the development and improvement of organic-finish testing instruments and methods. In addition to his work on conductive coatings, he has engaged in the development of high-quality protective finishes for wood and metal. Mr. Phair is a member of Tau Beta Pi, the New York Paint and Varnish Production Club, and the American Society for Testing Materials.

Thermo-Compression Bonding

Left to right: H. Christensen, O. L. Anderson and P. Andreatch, Jr., discuss the experimental equipment developed for thermo-compression bonds.

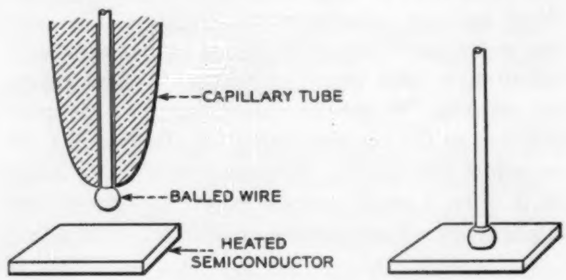
A significant break-through in the technique of attaching electrical leads to semiconductor devices has been achieved at Bell Laboratories. Research by O. L. Anderson, H. Christensen and P. Andreatch has shown that a combination of heat and pressure can be employed to provide a firm bond between various soft metals and clean, single-crystal semiconductor surfaces. Called thermo-compression bonding, this new technique provides a bond that is stronger than the lead itself. Temperatures and pressures required are not high enough to affect the electrical properties of the semiconductor material.

One method of forming a suitable bond is to employ a heated element such as a wedge, a flat or a point to press the metal against the heated semiconductor with a pressure sufficient to cause a slight deformation of the lead. Adhesion occurs within a matter of seconds. Another useful connection may be made by butting the balled (or headed) end of a wire against the heated semiconductor by means of a capillary tube.



The thermo-compression bonding technique: 5,000 to 10,000 psi pressure on wedge at temperature of 200-300°C produces mechanically strong bond.

Thermo-compression bonding has a number of advantages over other methods of attaching leads to semiconductors. The bond is stronger; the technique is more readily adaptable to mass production; no chemical flux or other chemical contaminant is involved in the process; and leads may be attached to much smaller areas, an invaluable aid in fabricating high-frequency transistors.

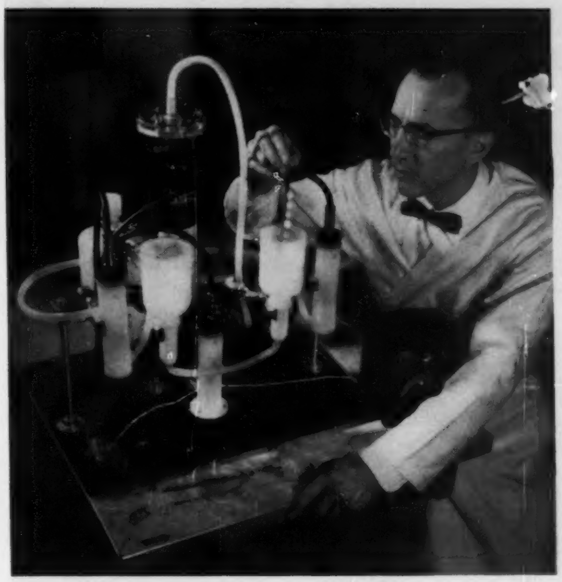


Pictorial representation of the thermo-compression bonding technique in which a balled wire is attached to a semiconductor material.

Adhesion takes place in seconds with pressures of a few thousand pounds per square inch and temperatures well below the melting point of the alloy of the metal and semiconductor. A gold-germanium bond appears to be the easiest to make, but gold, silver, aluminum and a number of alloys can be readily bonded to germanium or silicon.

Intensive investigations are underway to determine the mechanism of this bonding process, and to study further its practical applications. The technique is already being employed on a laboratory basis in the fabrication of transistors.

Cleaning Semiconductor Components



Miles V. Sullivan of the Laboratories inserting a number of transistors into the washing system.

A highly effective system for removing surface contamination from semiconductor components has been adapted from electron-tube techniques by Miles V. Sullivan of the Laboratories. This is a continuous water-washing system that completely removes all water-soluble materials which remain after etching, and that monitors the effectiveness of the washing procedure.

When used on transistors, the system has resulted in significant improvements in breakdown voltage, "sharpness" of voltage-current characteristics, saturation current, and emitter reverse impedance. Thus, it will contribute appreciably to the fabrication of semiconductor components having greater reliability and better operating characteristics, and will reduce the number of rejects.

Washing Technique

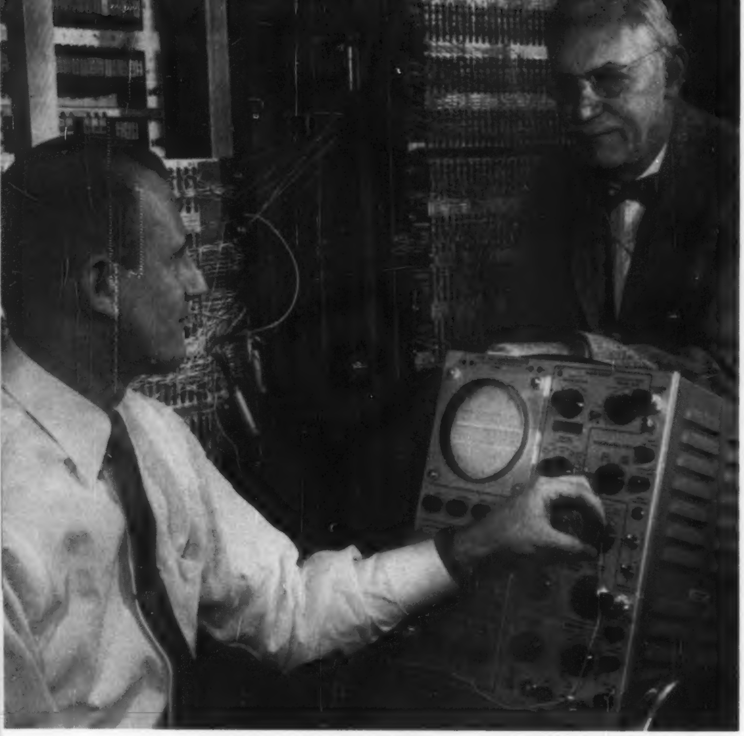
Distilled water, replaced about once a week, is continuously recirculated through the system at about two liters per minute. It first passes through a small deionizing column which reduces its conductivity to about 0.1 micromho per cm as measured in a conductivity cell. The deionized water then rises through a vertical standpipe in which the parts being cleaned are suspended on a stainless steel frame. After flowing over the upper edge of the standpipe, the water passes through a second conductivity cell and thence to a sump for recirculation through the system.

CO_2 is picked up from the air in the washing chamber, and increases the conductivity of the water in the system, from 0.1 micromho per cm in the first cell to 0.15 micromho per cm in the second. Thus, parts are washed until these two readings are obtained from the cells. Two minutes are generally sufficient, although washing is usually continued for five minutes. The thoroughness of washing is readily specified by the conductivity of the effluent, and this makes possible a one-hundred per cent "inspection" of the product.

Removes Soluble Inorganic Materials

This washing technique cannot be used as a substitute for cleanliness during the entire fabrication process. Contamination must be minimized by working in air-conditioned dust-free rooms, by preventing contact with bare hands, and also by using carefully selected and highly purified materials such as cements, cutting or grinding compounds, and etching solutions.

Ultra-sonic washing techniques can be successfully employed to remove physical contaminants such as dust and lint which are not chemically bonded to the surface; and use of non-polar organic processing materials minimizes the chemisorption or surface bonding of polar substances, thus allowing efficient removal by solvent extraction. The chemical etches customarily employed in semiconductor processing, however, produce relatively large amounts of soluble inorganic materials which are ionic and hence potentially detrimental. It is these materials which are effectively removed by the new washing system.



All of us use the decimal system every day and are familiar with its basic rules. The decimal system, however, is a very inefficient and complex mathematical language when used in computing machinery designed to do arithmetic automatically. Consequently, binary numbering systems, long familiar to mathematicians as a simple and efficient means of translating decimal numbers into another form, were adapted for computers. These computer "languages" have proved to be so successful that binary arithmetic has become an integral part of modern digital computer technology.

"Languages" of Digital Computers

A. W. HORTON, JR. *Switching Research*

Most of us are familiar with the ordinary desk adding and calculating machines, and every one of us has probably been handed a grocery bill in the form of a printed slip from an adding cash register. Yet, when we hear about the marvelous new electronic computers, we are amazed at the feats of which they are capable and the speed with which they perform their calculations. Actually, these marvels are only bigger, faster, and more complex versions of the familiar desk calculator. They perform their computations with numerical digits just as we do – they are digital computers.

A digital computer, somewhat over-simplified, is a calculating device consisting essentially of three parts – storage devices which receive information and return results, an arithmetic unit which performs the computations, and a control unit which instructs the computer in accordance with presupplied information.

Numbers and information must be supplied in a form the computer can understand. The "language" used by almost all digital computers is composed of "words" represented by groups of electrical impulses, or by the condition of devices capable of being in one or the other of two stable states. Examples of the latter are relays, which are either operated or unoperated; electron tubes, transistors, and diode gates, which are either conducting or non-conducting; and magnetic cores saturated in one direction or the other.

Any decimal digit from 0 through 9 could be represented by an electric pulse on one of ten wires, or by the operated condition of one of ten bi-stable devices. Or, by applying pulses serially on a single lead, as is done in dial pulsing, we would identify a digit by the presence of a pulse in any one of ten time-sequence positions. This is not, however, the most efficient way of coding numbers for the "thought" processes of the computer.

We count by ten's because we have ten fingers on our hands. This is the natural way to count, but it is not the only way. Merchants count by the dozen and the gross; surveyors and navigators by seconds, minutes and degrees. There is even a group of earnest thinkers who believe we would be better off if we were to use the duo-decimal system and count by twelve's.

It seems wasteful to have to use ten pulses or operate ten devices to represent the decimal digits if the job can be done with fewer pulses or opera-

tions. Following the decimal dogma seems particularly inefficient when one considers that by using only four bi-stable devices, there are sixteen possible combinations of the operated or non-operated condition, including the all-position-vacant combination. But is there a way of assigning one of these combinations to each of the digits 0 to 9 so that the logical rules for arithmetic will be obeyed? There are several ways, but the simplest is the arrangement known to mathematicians as the *binary number system.* In this system, we count by two's instead of by ten's as in the familiar decimal number system.

When we count by ten's, numbers less than ten are represented by the numerals 0 through 9. When a number is greater than 9 we "carry" to the next place to the left and start a digit position with a new meaning. Thus, 14 is the representation of $10 + 4$. Similarly, a larger number such as 796 is the representation of $700 + 90 + 6$, which in turn is the representation of $7 \times 10^2 + 9 \times 10^1 + 6 \times 10^0$. The base, or radix, is 10 and the position of each digit in a number represents the power to which the radix is raised.

In representing a number in the *binary scale of notation,* the representation is as a sum of ascending power of two, each multiplied by an integer – either zero or one. For example:

$$1\times2^5+0\times2^4+1\times2^3+1\times2^2+0\times2^1+1\times2^0=45$$
$$32 + 0 + 8 + 4 + 0 + 1 = 45$$

and is written as 101101. In the binary representation, the position of the digit indicates the power of the radix (two), just as in the decimal system it represents the power of base ten. In general terms, the computer represents 1 by a device in the conducting or operating state and 0 as the non-operating state.

The binary scale of notation represents individual decimal digits as shown at the left in Figure 1. A number such as 205 can also, therefore, be represented as:

2	0	5
0010	0000	0101

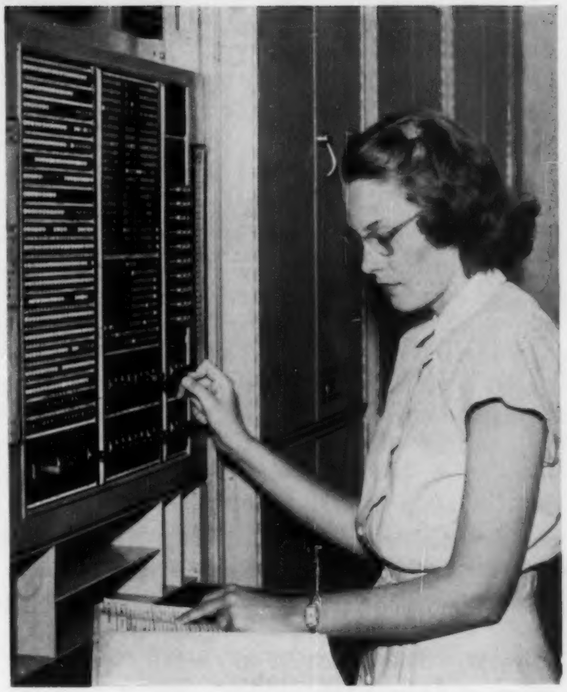


Fig. 2 — Miss Betty Boyd putting problem information into the Bell Laboratories Model V relay computer. These early computers used electromechanical computing elements, and required large rooms full of relay racks for their operation.

This alternative form of binary representation is known as the *binary-coded decimal system.* Any number can be expressed by simply representing the individual digits that make up the number in binary form. The rules for arithmetic in this system are similar to those for decimal arithmetic and the system is easy to memorize and to use. The binary-coded decimal system is employed in a large number of electronic computers.

Straight binary representation of numbers, however, is somewhat more efficient for computer storage devices than the binary-coded decimal system. If we wish to compute to six places, for instance, we need $4\times6=24$ binary elements using the binary-

0	0000	5	0101	0	0000 + 0011 = 0011	5	0101 + 0011 = 1000	0	01	00001	5	10	00001
1	0001	6	0110	1	0001 + 0011 = 0100	6	0110 + 0011 = 1001	1	01	00010	6	10	00010
2	0010	7	0111	2	0010 + 0011 = 0101	7	0111 + 0011 = 1010	2	01	00100	7	10	00100
3	0011	8	1000	3	0011 + 0011 = 0110	8	1000 + 0011 = 1011	3	01	01000	8	10	01000
4	0100	9	1001	4	0100 + 0011 = 0111	9	1001 + 0011 = 1100	4	01	10000	9	10	10000

Fig. 1 — Left, representation of the ten decimal digits using the binary scale of notation. Center, binary three (0011) is added to regular binary coded representation of the decimal digits to produce the excess-three code. Right, bi-quinary code is used in some digital computers to help ensure reliability in digit registration.

coded decimal system. Since $2^{20} = 1,048,576$, we can obtain the same accuracy with only 20 storage elements by using the binary scale of notation. For 205, used in the previous example, the binary conversion is:

Decimal Number	*Equals*	*Binary Number*
128		1×2^7
+ 64		$+1 \times 2^6$
+ 0		$+0 \times 2^5$
+ 0		$+0 \times 2^4$
+ 8		$+1 \times 2^3$
+ 4		$+1 \times 2^2$
+ 0		$+0 \times 2^1$
+ 1		$+1 \times 2^0$
205		205

and the number is represented as 11001101.

So far we have considered two forms of binary notation. Actually, the number of ways of using binary and other notation schemes is almost infinite, so we will touch on only a few of the more useful and significant coding systems. Another method of encoding decimal digits, for example, is the "excess-three code", used in the Bell Laboratories Computer Model I. This scheme is derived from the binary-coded representation by adding three to each digit as shown in Figure 1, center. The use of this code produces the correct decimal carry when performing addition and lends itself readily to the representation of negative numbers. A further advantage is that all digits have at least one "1" in their representation so that the all-positions-vacant condition can be readily distinguished from zero. A disadvantage is that a correction must be made when performing addition or subtraction, because of the excess-3 added to each digit.

It is extremely desirable to ensure reliable operation of a computer, and in many cases it may be worthwhile to obtain reliability by means of additional equipment. One way of doing this is to use a "parity check". This consists of an added checking digit which makes the total number of 1's present either even or odd, depending on the checking system. Errors are automatically detected when the checking condition is not fulfilled. Another way is to use a code which represents each digit with the same number of 1's. The *bi-quinary code,* used in later Bell Laboratories relay computers, is an example of such a code. As shown in Figure 1, right, the seven relays for each digit are divided into two groups. One relay, and only one, in each group must close to represent a valid number. The first group of two relays indicates whether the number is less than five, or equal to or greater than five. The second group then identifies the digit. If more or less than two relays close an error has been made.

The discussion so far has been restricted to positive integers. Most problems, however, require the use of both positive and negative non-integral numbers. This means that we must keep track of the

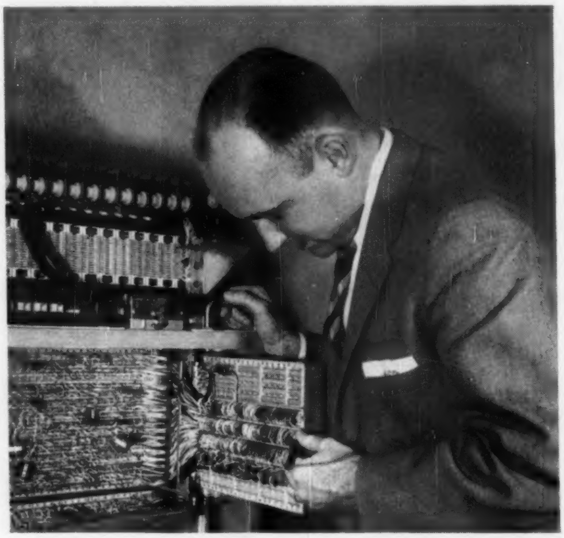


Fig. 3 — J. A. Githens inspecting circuit of the "Leprechaun" digital computer.

position of the decimal or binary point. In later models of Bell Laboratories relay computers, this is done by carrying extra digits to indicate the power of ten by which the number must be multiplied. It can also be done by keeping the decimal point fixed and multiplying all input numbers by an appropriate factor of ten so that all computed quantities can be expressed with the same fixed decimal point. The TRADIC* and the "Leprechaun"† digital computers – designed by the Laboratories for the Air Force – represent all quantities by numbers less than one, with the binary point at the left immediately in front of the most significant digit of the number. The place to the left of the binary point is used to indicate the sign of the number following the decimal point.

Negative numbers may be represented by their absolute values prefixed by a minus sign. The more recent relay computers designed in the Laboratories and many other digital computers use this representation, employing an extra pulse to represent the

*RECORD, *April,* 1955, *page* 155. † RECORD, *July,* 1957, *page* 272.

sign. To add a positive number to a negative number, however, the computer must first determine which is the greater in absolute value. If the positive number is larger the procedure is to subtract the absolute value of the negative number from it and obtain a positive result. If the reverse is true, we must subtract the positive number from the absolute value of the negative number and the result is negative. This procedure is somewhat awkward to implement since it involves a choice of two alternative actions of the computer based on a comparison of the two numbers.

This awkward situation can be avoided by representing negative numbers by their complements, which are positive. The true complement of a number is obtained by subtracting the number from the most significant place in the number. For example, the true complement of 45 with respect to the base raised to a power at least one greater than 100 is 55, with respect to 1000 is 955, and so on. When the power of the base is two greater than the most significant place, there will always be a 9 in the most significant place in the complement, and this can be used to identify the complementary representation of a negative number.

Subtraction may be performed as the addition of two positive numbers by converting the number to be subtracted to its complement. If the result is positive, the most significant digit will be a 1 which must be discarded. A negative difference will be indicated by a 9 in the most significant place, and the complement must be taken to obtain the true magnitude of the result. For example, to subtract 23 from 45, take the complement of 23, which is 977 and add:

$$\begin{array}{r} 45 \\ -23 \\ \hline 22 \end{array} \qquad \begin{array}{r} 45 \\ +977 \\ \hline (1)022 \end{array}$$

The (1) is to be discarded and in this example the 0 need not be written. To subtract 233 from 45:

$$\begin{array}{r} 45 \\ -233 \\ \hline -178 \end{array} \qquad \begin{array}{r} 45 \\ +9777 \\ \hline 9822 \end{array}$$

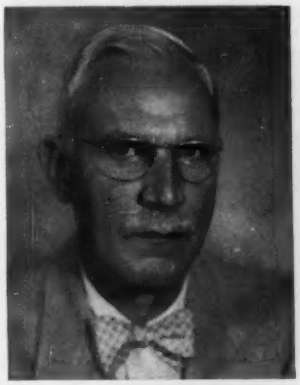
and the complement of 9822 is —178.

Identical considerations apply to numbers represented in binary form except that a power of two must be used instead of a power of ten, and the representation is known as the *two's complement*. A simple rule for taking the two's complement of a number in this language is to change 1's to 0's and 0's to 1's, add 1 in the least significant place and perform the indicated carries. The Tradic uses these representations of negative numbers, but performs subtraction in the usual manner as the inverse of addition.

Another form of complementary representation, used in Laboratories' relay computers, is the "nine's" or "one's" complement in decimal or binary notation. It has found favor because it is derived by subtracting each digit from either 9 or 1.

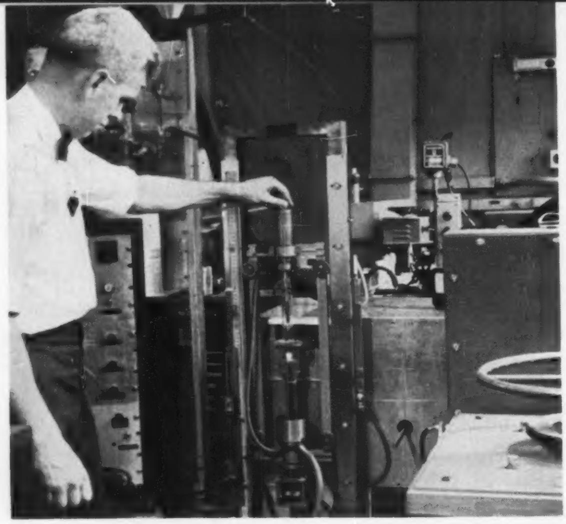
These, briefly, are some of the languages, or binary coding systems, used by digital computers. The literature – arithmetic computations – computers can produce from these languages has been hinted at by simple examples of addition and subtraction. Other languages are in use, but those discussed here are the most prevalent. In fact, nearly all modern high-speed electronic computers use binary representation of digits. Other common arithmetic computations – multiplication and division – can be performed by successive addition and subtraction. All of the more complicated computations of modern science and engineering can be performed in terms of these elementary arithmetic operations.

THE AUTHOR



A. W. Horton, Jr., a native of Philadelphia, joined the Laboratories in 1922. He was awarded the A.B. and E.E. degrees by Princeton University in 1920 and 1922. During his first fifteen years at the Laboratories, he was concerned with telegraph, picture and television transmission and voice-operated equipment, such as transatlantic radio terminals and echo supressors. A member of the National Defense Research Committee during World War II, he worked on underwater sound equipment and naval antiaircraft fire control systems. He is currently the head of a subdepartment engaged in military systems research and theoretical switching studies. Mr. Horton is a consultant for the Department of Defense, and a member of the I.R.E., the American Physical Society, the American Institute of Physics and the Association for Computing Machinery.

Automatic Floating-Zone Refining



Ernest Buehler adjusting the equipment for automatic floating-zone refining of various materials.

An automatic refining device which will reduce electrically active impurities in silicon to less than one part in one billion has been developed at Bell Laboratories. It uses the floating-zone refining technique in which a molten zone is swept through the silicon, carrying impurities with it. The method can also be used to purify germanium, molybdenum, tungsten, and many other materials.

The new level of purity made possible by this device may lead the way to the manufacture of improved transistors, diodes and other semiconductor devices. It also will assist in completing an evaluation of the intrinsic properties of silicon and will permit a better understanding of conduction properties in high-resistivity semiconductors.

Zone refining, developed at Bell Laboratories,* makes use of the fact that most impurities are more soluble in molten than in solid material. Thus, a molten zone swept along a rod of silicon will accumulate impurities from the silicon. The technique is being successfully applied to refining a growing number of materials: metallic, inorganic, and organic.

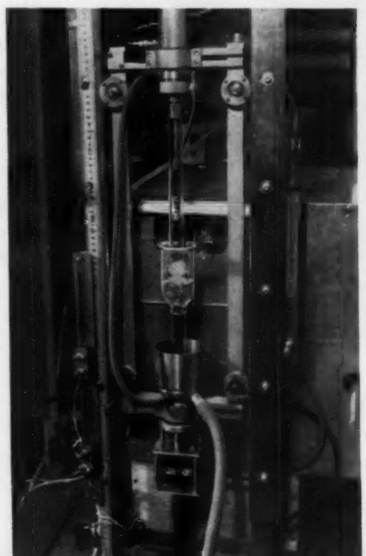
Eliminates Crucible

No satisfactory solid material has been found, however, for use as a crucible containing silicon during the refining process. Fused silica, frequently used for the crucible in zone refining, is attacked by molten silicon. For example, contact with commercial fused silica for one hour introduces about one to three parts per billion of electrically active impurities to molten silicon at 1,450°C. An advantage of the floating-zone process is that it requires no crucible and so is free from such contamination. In this process, the molten zone, supported only by surface tension, is passed along a vertical silicon rod rigidly held at both ends. Refining is performed in a controlled atmosphere by surrounding the rod with a water-cooled, gas-tight envelope. Inductive heating produces the molten zone, and motion of either the heating coil or the rod sweeps the zone along. This process is repeated, with the molten zone always traversing the rod in the same direction, until the desired purity is obtained in the silicon.

The new automatic apparatus consists of a 10-kilowatt, 4-megacycle generator, a mechanical method of moving the rod up and down while it is rotating inside a gas-tight silica enclosure, and switching circuits that are used for automatically recycling the mechanism.

Initially, because of its high resistivity, the end of the silicon rod must be raised in temperature to about 800°C by conduction from a molybdenum chuck which is heated by the radio-frequency generator. Thereafter, power is absorbed by the rod itself, and all subsequent operations are automatic. The power is increased to a preset value, sufficient to produce the desired molten zone at a preset location, and the motor-drives for the mechanism are started. These drives rotate the rod and move it downward, so that the molten zone traverses the

A crystal of silicon being refined by the automatic floating-zone refining equipment.



* Record, *June*, 1955, *page* 201.

rotating rod from bottom to top. When the zone reaches the top of the rod, a limit switch stops the rotation and decreases the power to a preset value sufficient to keep the heated but now solidified zone at about 1,200°C. This heated zone is then returned to its previous position near the bottom of the rod as the rod is raised by the drive mechanism. There, a limit switch raises the power to the preset value for melting, starts the rod rotating, and reverses its direction of travel. The automatic recycling continues as long as required.

Purest Silicon

Constant length and freedom from mechanical oscillation of the molten zone have been achieved by employing a low heating current at a relatively high frequency and by properly proportioning the load and generator impedances. Low currents minimize electromagnetic levitation forces, the high frequency increases power-transfer efficiency, and a load-to-generator impedance ratio less than unity stabilizes zone length. The load impedance decreases as the rod melts, so that as the zone tends to lengthen, less power is put into the load and the temperature drops, thus tending to decrease zone length. Crystals of uniform diameter are secured by control of the ratio of zone length to rod diameter, so that the upward transport of material by the molten zone is balanced by the oppositely directed gravitational force.

By use of this equipment with a moist hydrogen atmosphere to remove boron, a single crystal of *p*-type silicon with a resistivity of 16,000 ohm-centimeters and minority-carrier lifetime of 1,200 microseconds has been obtained after 67 passes. This corresponds to an impurity content of less than one part per billion, thought to be the purest silicon ever produced in quantity.

Pocket-Radio Signaling

A personal signaling service, described as a kind of extension of the telephone bell, has been introduced experimentally in the Allentown-Bethlehem area by the Bell Telephone Company of Pennsylvania. In connection with the trial, Bell Laboratories has engaged in studies of equipment performance, maintenance techniques and radio propagation to determine coverage.

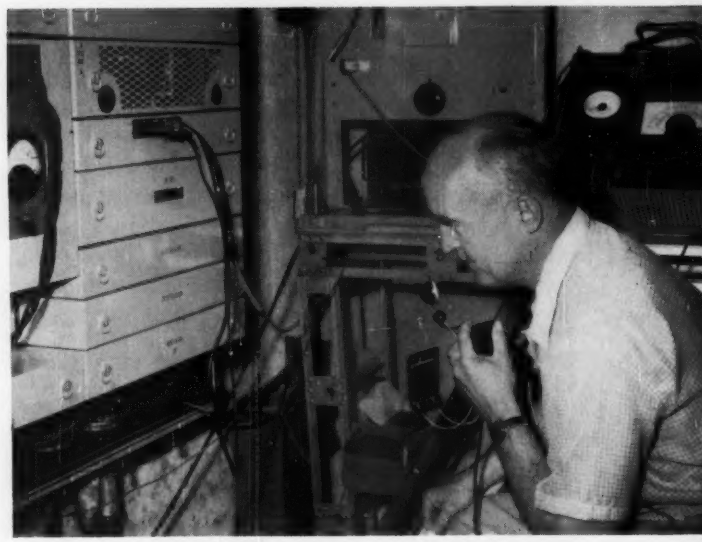
First of its type to be offered to the public by the Bell System, the service uses a transistorized radio-receiving set somewhat larger than a king-size cigarette package. The set is tuned to a fixed frequency and operates over a range of a few miles. Clipped to one's belt or on the inside of a pocket, the device informs a person that there is an important message for him at his office or home.

The service is expected to appeal particularly to doctors, repairmen, deliverymen, lawyers, salesmen and others who want to keep in touch with their offices. The system in the test area is capable of handling about 3,000 receivers. The pocket sets are rented to customers.

In practice, the service works like this: a secretary wishes to get an important message to Dr. Jones. She calls a special telephone operator known as the signaling operator, and gives her the number of Dr. Jones' receiver. The operator "dials" the number, and voice-frequency pulses go out over the radio channel to activate four reeds in Dr. Jones' receiver. Only his receiver responds to the particular signal. The reeds trigger an oscillator, and Dr. Jones hears a pleasant tone coming from his coat pocket. Alerted that he has a call, he goes to the nearest telephone booth and calls his office or a predetermined telephone number.

Small transistorized receiver responds to individual customer's radio signal, informing him that he has a telephone call. Service is still experimental.

One fundamental problem in the design of any communications system is that of allocating frequency space for the necessary channels within the available useful bandwidth of the transmission medium used. In the Laboratories design of the communications system for the Air Force Missile Test Center, the solution to this problem required considerable ingenuity. In this system, a single submarine cable had to be arranged for two-way transmission of a variety of signals, including telemetering signals, telephone messages, and timing pulses.



Transmission Features of the USAF Submarine Cable System

L. M. ILGENFRITZ *Transmission Systems Development II*

Although much of the Laboratories design of the submarine cable system for the Air Force Missile Test Center* was based on previously existing apparatus and techniques, special communications requirements for guided missile testing over the long ranges involved presented a number of unique problems. It was decided that these communication problems could be solved best by using a submarine cable extending about 1,350 miles from Cape Canaveral, Florida, southeastward to Puerto Rico. To provide the required service as economically as possible, it was further decided that communications in both directions would be transmitted over a single cable.

Basically, the system was designed for eleven telemetering channels in the up-range direction (northwesterly) and one in the down-range direction; twelve telephone channels in each direction; one program channel in each direction; and facilities for an order-wire circuit, timing-pulse circuit, synchronizing tone, and dc power distribution. The cable is a coaxial type with a single central conductor, and therefore, carrier current methods had to be used for nearly all the transmission facilities. Since only one cable was to be made available, "equivalent four-wire operation" is used for these carrier channels; one band of frequencies is used for transmission in one direction, and another band for transmission in the opposite direction.

To obtain a reasonable compromise between the needed bandwidth in the cable and the distances separating suitable repeater sites, the system has been designed to operate at frequencies up to 150 kc with the length of the cable sections limited to about 70 nautical miles. This means that usually two auxiliary repeaters had to be used between each pair of observation stations. The frequency allocations of the various channels designed to make the most effective use of the cable are shown in Figure 1. A broad channel was established at the upper end of the frequency range for transmitting telemetering signals from "down range" back to the launching site. A missile in flight may contain a telemetering radio transmitter which sends out its signals to be picked up by the radio receivers at the nearest observation station and then relayed back to the site over the cable.

* RECORD, *September*, 1956, *page* 321.

The telemetering channel allocation for guided missiles was standardized some years ago by the Research and Development Board. It includes eighteen channels ranging in frequency from 0.4 to 70 kc. This range is too wide to be used on the cable system without sacrificing an excessive number of other communication channels. A compromise was therefore agreed upon based on the use of eleven of the eighteen channels (numbers 6 through 16 inclusive) requiring a band extending from about 1.5 to 46 kc. The cable system was designed, however, to transmit the telemetering channels at the upper end of the frequency band to minimize the difficult problem of equalizing severe delay distortion. The original telemetering channel frequencies are, therefore, modulated on a 104-kc carrier and only the upper side-band is used. This results in telemetering channel frequencies extending from about 105.5 to 150 kc.

As a missile progresses down range from one observation station to another, the telemetering band at the up-range station is switched to a through connection so that transmission from the next down-range station is given a clear path. It is important that the quantitative information contained in these telemetered signals be transmitted as accurately as possible by the cable system. Hence, the telemetering channel band has been designed so that the total error in the telemetered signals caused by the cable system is less than two per cent in any of the channels.

In addition to those mentioned, one telemetering channel was required in the down-range direction, chiefly for calibrating elements in the system. Telemetering channel 12 (center frequency – 10.5 kc) was chosen for this purpose, and is transmitted, when necessary, without shifting its frequency. When used, it displaces only two telephone channels. In this band it is not possible to meet the two per cent accuracy requirement for full load and signal speed, but it is met for all combinations of load and speed up to about 90 per cent of the maximum rating.

The standard 12-channel bank carrier equipment used on J, K and L systems is employed as the basic building block for the carrier telephone channels. This provides twelve high-grade telephone channels at 4 kc intervals between 60 and 108 kc for one direction of transmission. Telephone channels are also group modulated downward in frequency to the 4 to 52 kc range. This provides the twelve channels required for telephone communication in the opposite direction. Since transmission of the high-frequency telemetering signals was to be back toward the launching area, it was decided that all high frequencies should be transmitted in that direction. The 12-channel telephone group between 60 and 108 kc was therefore assigned to up-range transmission, and the 4 to 52 kc group to the down-range direction. The 8-kc gap (52 to 60 kc) between the two 12-channel telephone groups is required to build up loss in high- and low-pass direc-

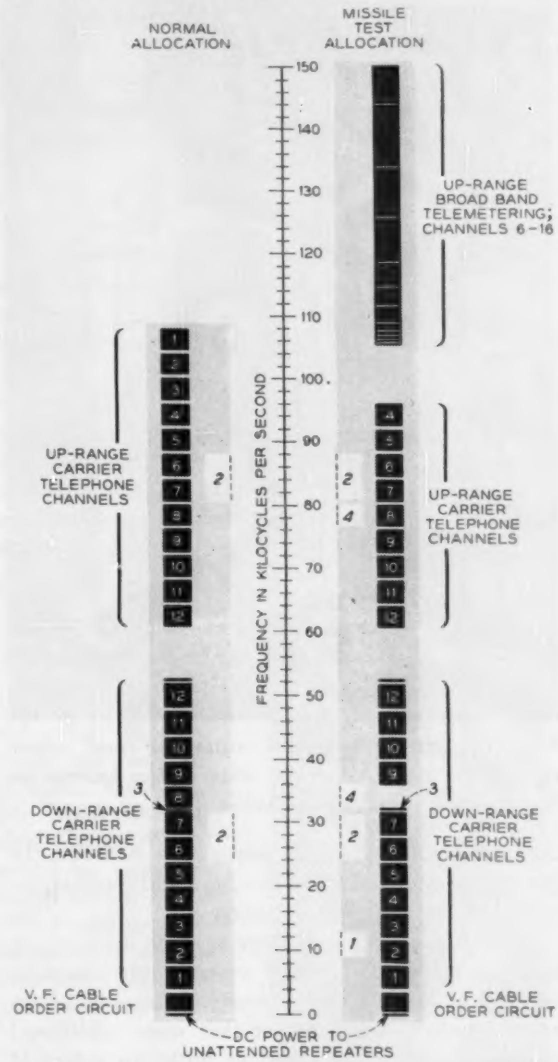


Fig. 1 — Frequency allocations for various channels in the Air Force cable. 1. Telemetering channel 12 for down-range transmission. 2. Program band for either up- or down-range transmission. 3. Synchronizing frequency, 32 kc. 4. Channel 8 down range transmits range timing pulses with the normal 80-kc carrier shifted to 72 kc. Up-range channel is used for checking purposes.

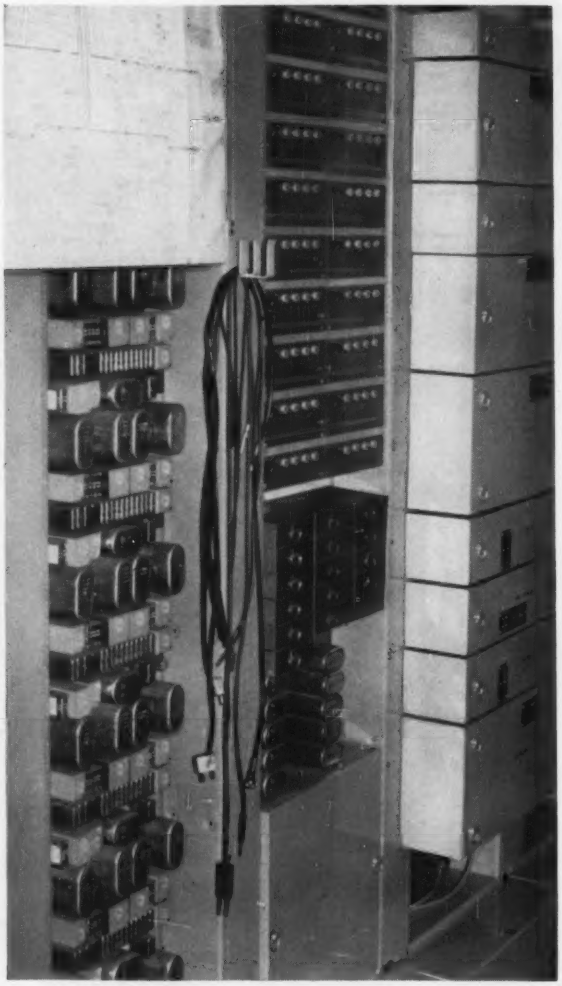


Fig. 2 — Special channel equalizer and other equipment installed at an observation station on the Air Force submarine cable.

tional filters for adequate separation between the groups transmitted in one direction and those transmitted in the opposite direction

As shown in Figure 1, there is some overlapping between the low-frequency telemetering channels and the high-frequency, up-range telephone channels. Coupled with the fact that some additional frequency range is required to build up sufficient selectivity in the telemetering channel filters, this means that the up-range telephone channels numbered 1, 2, and 3 cannot be used while telemetering signals are being transmitted. The single down-range telemetering channel also prevents the use of down-range telephone channels 2 and 3 while the telemetering channel is in operation.

A standard 5-kc carrier program channel which replaces telephone channels 6 and 7 was also required. This is equipped for local control and it may be used in either direction, but equipment has not been provided for transmission in both directions simultaneously. In the voice-frequency band, an independent order wire circuit was established to enable maintenance personnel at normally unattended repeater huts to communicate with each other and with attended observation stations. This circuit is equipped with loudspeaker monitoring and selective signaling between observation stations. The unattended repeaters are powered by direct current which is transmitted over the cable from the nearest observation station.

The Air Force had requested that a special channel be provided for the transmission of range timing pulses, and further, that an effort be made to determine the transmission time between the launching area and each observation station to an accuracy of 50 microseconds. Pulse transmission was to be held well within that accuracy over long periods. For local transmission of short steep timing pulses there is no great incentive to restrict bandwidth. But where it is necessary to transmit pulses for more than 1,000 miles over a cable system that costs more than one hundred thousand dollars per kilocycle of bandwidth, it becomes important to use a minimum bandwidth.

The required accuracy was achieved on a carrier telephone channel without delay correction by a process in which the accuracy of pulse timing is preserved in a narrow band, but the pulse rate is limited. The range timing pulse transmission circuit and a useful set of testing equipment which resulted as a by-product of this development will be described in a subsequent Record article.

If the power supplying one or more intermediate repeaters should fail, relays automatically connect the hybrid transformers and bypass the amplifier equipment at these repeaters. As a result, voice-frequency transmission is still possible for distances of more than 100 miles, but transmission losses are considerably increased.

The carrier channels are equipped with ringdown signaling where the system is operated through local switchboards. Conference circuits are also provided by four specially designed terminating sets at each attended station. Each of these sets makes it possible to connect one or two telephones to a telephone channel at every attended station, if desired. Push-to-talk operation is not required, and excellent balances are maintained.

At attended observation stations, it was not feasi-

ble to locate the carrier equipment at the shore line, nor was it feasible to bring the submarine cable overland to the terminal building. For this reason, huts were built at the shore line to terminate the submarine cable and separate the dc, voice and carrier paths into physical 4-wire circuits. To connect the huts and control buildings over distances of from one quarter to seven miles, a land-type cable was used. At the Mayaguana observation station,* however, the adjacent cable sections were so long that some of the amplifiers had to be placed in the filter huts to preserve good signal-to-noise ratios. These amplifiers were powered by direct current from the Mayaguana office over additional pairs in the land cables used there.

In the portion of the system between Grand Turk Island and Puerto Rico, there are two unattended repeater stations that required special treatment. This was because there are no islands between the Turks Group, the farthest south of the Bahamas, and the Dominican Republic. Since the shortest feasible cable distance, about 93 nautical miles, was too long a span to provide the required facilities in a single cable, two cables were laid and one-way transmission in each cable was resorted to in this section. With this two-cable transmission arrangement, the maximum frequency on each cable is lower than it is in an equivalent one-cable system, and hence the transmission loss per mile is less at the highest transmitted frequencies. As a result of this modification, the repeaters at Sand Cay and Puerto Maimon had to convert from equivalent 4-wire to physical 4-wire operation and vice versa. This requires double group modulation in one direction at each of these repeaters. For carrier supply at these points, a low-level 52-kc frequency is transmitted from the regular carrier supply at Grand Turk, and at these repeaters the group modulation is performed by using the fifth and sixth harmonics of this frequency.

The channel noise requirements of the system have been met with some margin. As anticipated, most of the time the chief noise source is thermal agitation in the cable-terminating resistances. At other times some static may be present. There is no appreciable modulation noise beyond that normally obtained from the channel banks, which is negligible. During the many months in which this system has been operating, which include two heavy static seasons for the portion north of Grand Turk and one heavy static season for the entire system, the one per cent static noise objective, usually engineered for in systems of this type, has been substantially bettered. This performance is gratifying in view of the high static incidence in this part of the world and the large number of cable exposures at shallow water landings.

* See map, Record, *September, 1956, page* 322.

THE AUTHOR

L. M. Ilgenfritz, a native of Monroe, Mich., received a B.S. degree in Electrical Engineering from the University of Michigan in 1920. He joined the Development and Research Department of the A.T.&T. Co. in that same year, and transferred to Bell Telephone Laboratories in 1934. Mr. Ilgenfritz's work has been concerned with transmission development, except during World War II when his effort was concentrated on war work. Since the war he has supervised the transmission design of the submarine repeaters and terminals for the Nos. 5 and 6 Key West-Havana cable systems, and subsequently, the transmission designs of the systems for the Florida-Puerto Rico cable for the Air Force and the Ketchikan-Skagway submarine cables for the Alaska Communications System. He is currently engaged in further transmission studies in connection with submarine cable systems both for Bell System and for government use.

Distinctive Ringing Signals for the 500 Set

R. T. JENKINS
Station Apparatus Development

In a large business office, or in other situations where two or more telephones are in the same room, it is a great convenience if each telephone has its own distinctive ringing signal. In this way the user can recognize his telephone even when he is away from his desk and when other telephones are ringing at the same time. By the use of different metals of varying thicknesses, Laboratories engineers have developed a series of gongs to provide up to seven distinct ringing signals.

Gongs and bells have been used for centuries to attract attention and to call people together. Their continued popularity is largely due to their inherent qualities as sound generators and to the fact that they can be very distinctive. Distinctiveness involves several factors. One of these is pitch – an auditory sensation related to frequency, sound pressure, and wave form – whose value is established by comparison with a simple tone. Although pitch is related to the fundamental frequency of the sounding device, the two are not necessarily identical. Fundamental frequency is related to the dimensions of the gong, and in general the larger gongs have lower fundamental frequencies. Large gongs are also efficient radiators of sound.

Another distinctive feature of gongs and bells is that all such devices radiate a complex sound that includes many overtones, which gives each its own individual tone quality. Besides these factors of pitch and quality, gongs and bells can also acquire distinctiveness from the code or sequence with which the clapper is allowed to strike and by virtue of the directional properties of the sound that is being radiated.

Gongs were therefore a natural selection for producing audible signals to summon users to the telephone. Usually, two gongs of different pitch are incorporated into a telephone ringer and are sounded by a vibrating clapper driven by an electromagnet. Such ringers perform their function of providing an attention-attracting and pleasant sound, but with uniform installation of ringers it is sometimes impossible to distinguish the signal of a particular telephone from others in the immediate vicinity. Since increasingly large numbers of telephones are now used at some locations, Bell Laboratories has been engaged in developing a series of gongs, so that several different ringers can be installed in the various telephones in a room to permit each user to recognize his own signal.

Of the many ways of achieving a distinctive ringing signal, gongs of different pitch offered the most attractive possibilities for this particular application. The metal of a gong can be cut in various ways to alter the sound, and snubber attachments can be used, but these methods affect ringer performance adversely. Resonating the fundamental frequency of a gong suggests another possibility, but this could provide at best only two or three distinctive tones.

For gongs used in the 500-type telephone set ringer,* the distinctive pitch is largely determined by the fundamental frequency of the gong. Superimposed upon the fundamental are many overtone frequencies, but, unlike the simpler sound spectra of some musical instruments, these overtones are not harmonically related. That is, their frequencies are not whole multiples of the fundamental. For example, the first overtone is about 2.6 times the fundamental and the second is about 4.7. It is this order of component relationships that gives these gongs their characteristic tone quality.

Despite this complexity of the sound, however, distinctiveness in these gongs largely results from the magnitude of the interval between the fundamental frequency of one gong and the fundamental frequency of another. In other words, if the fundamental frequencies of two gongs should differ in a ratio as much as 2:1, the two will be generally distinguishable, but if the frequency ratio is quite small, say 9:8, we might have difficulty telling one from the other. Precise information on this point was necessary before determining the

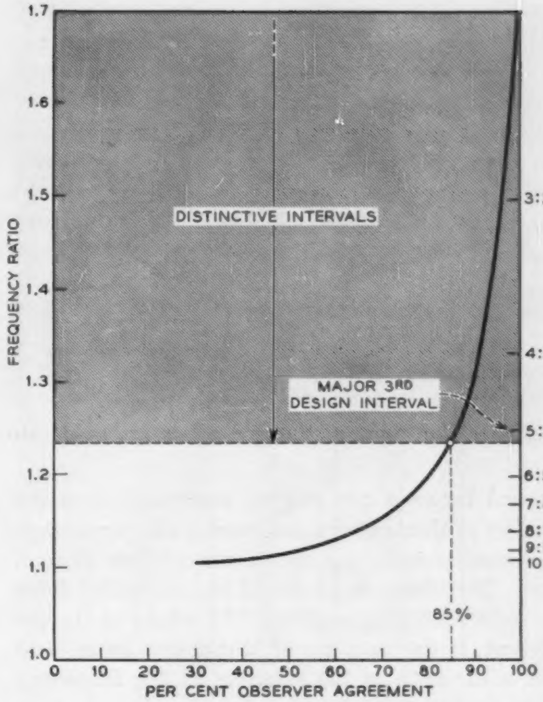


Fig. 1 — Frequency interval between two gongs versus per cent agreement on distinctiveness among twenty observers; 85 per cent agreement determined design interval of a musical third.

pitch interval for a specific design of gongs, which in turn determines how many different gongs could be supplied within a frequency range practicable in a telephone set (about 800 to 4,000 cycles per second).

To determine a distinctive pitch interval, listening tests were conducted using ringers covering a range of fundamental frequencies from 1240 to 3,570 cycles per second. Two gongs were used on each ringer. In some cases these two gongs were of the same fundamental frequency; in others the two were of different fundamental frequencies as in the 300- and 500-type telephone sets. In the latter two-gong combinations, the pitch frequency is closely that of the lower of the fundamental frequencies.

Twenty observers with normal hearing participated in the listening tests, and the results were scored according to observer opinion as to whether ringers, compared two at a time, were or were not distinctive. Each ringer of the series was compared with every other ringer. It was decided that two ringers were sufficiently distinct from each other if 85 per cent of the listeners could distinguish between them. Figure 1 shows the frequency

* RECORD, *October*, 1951, *page* 471.

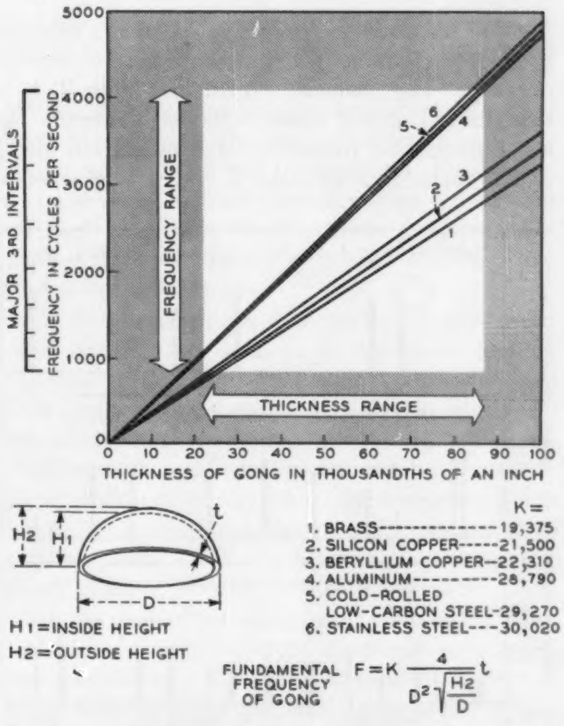


Fig. 2 — Graphs of six possible metals for distinctive gongs, relating thickness to fundamental frequency according to the design formula.

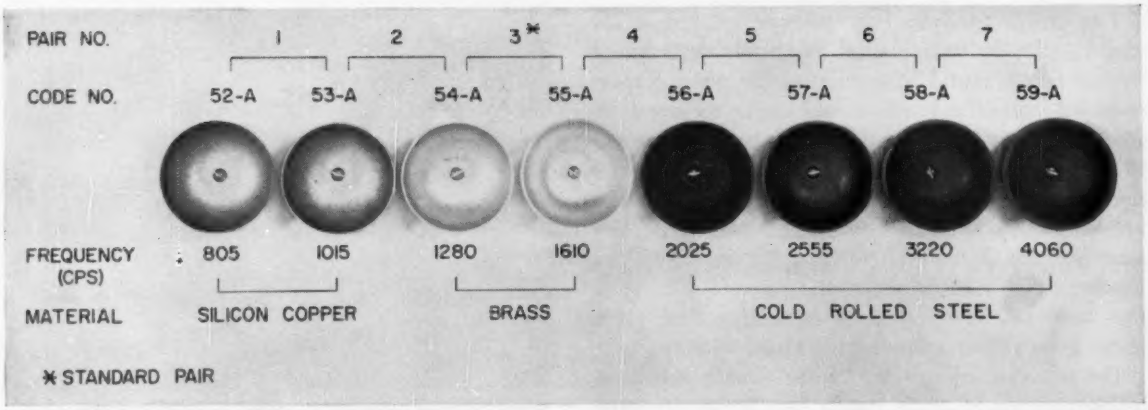


Fig. 3 — The eight distinctive gongs grouped into seven ringer pairs. Brass gongs are in 500 set ringer.

interval between two ringers, computed from the number of distinctive tones, versus the percentage of observers in agreement on the number of such tones. The distinctive interval was computed from the relationship $A = 2.88^{1/(n-1)}$ where A is the interval, n the number of distinctive tones, and 2.88 is the ratio of the extremes of the frequency range used in the tests.

On this basis, it was found that two ringers are distinctive if their fundamental frequencies stand in a minimum ratio of 1.24, or about 5:4. The 5:4 ratio closely approximates the interval which in musical terminology is referred to as a major third – for example, the interval included by the notes C and E on a piano keyboard.

Ten experimental ringers spaced a musical third apart were then tested in the presence of various types of noise. Each of these ringers was equipped with two gongs of nearly the same fundamental frequency, ranging from 425 to 3,530 cycles per second. Twenty observers with normal hearing and sixteen with deficient hearing participated. Distinctiveness for these tests was based on the observer's ability to distinguish a given ringer 75 per cent of the time. Results showed that for general-type noise (simulated room noise and other common noises) up to a 70-lb level, all ten test ringers were judged to be distinctive by 85 per cent of the observers in each group. Similar results were obtained for flat-type noise (wide-frequency noise like that from escaping air, running water, and vacuum cleaners), except that at the highest noise level of 70 db, a maximum of nine ringers were judged distinctive by the participants with normal hearing. Those with deficient hearing were still able to distinguish all ten ringers.

On the basis of these studies, a series of distinctive-tone gongs with the musical third relationship was designed for the 500 set ringer. Since the gongs used are of circular cross-section, and since all must be interchangeable on the ringer, a design requirement was that all gongs have the same outside diameter and inside height (see drawing of gong in Figure 2). Therefore, the only variables for obtaining different frequencies were the metal used in fabricating the gongs and the thickness of this metal.

All of the above factors are included in a formula used to determine the fundamental frequencies of gongs. This formula, shown in Figure 2, is a modification of the classical Rayleigh formula for the fundamental frequency of a cylindrical shell, and it includes a constant K which is character-

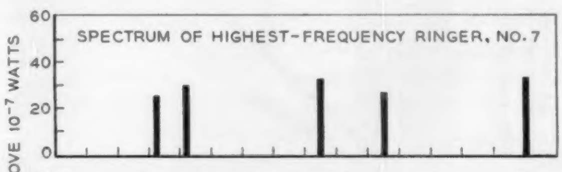


Fig. 4 — Sound spectra of the lowest, standard and highest frequency distinctive ringers.

istic of the metal. The dimension H_2 in the formula refers to the outside height of the gong, rather than the inside height used as a design requirement.

In practice, the range of available thicknesses is limited. If the gong is too thin, it is easily deformed, and if it is too thick, it is difficult to fabricate and will not fit over the resonators incorporated into standard ringers. The range of thickness used is from 0.022 inch to 0.087 inch, a ratio of about 4 to 1, which is insufficient to cover the desired frequency range. It was therefore necessary to use more than one metal for the gongs.

Many metals and metal alloys can be considered, and six are graphed in Figure 2. This illustration shows how types of metal and thickness of metal are related to fundamental frequency by the design formula. It also shows how metals must be chosen so that an optimum number of gongs of the musical third interval may be accommodated within any given range of frequencies.

Among other considerations governing the choice of metals, the temper of the metal must be adaptable to the forming process used in fabricating the gongs. Further, the metal must permit a satisfactory "decay rate" of sound output at a given frequency. (The reason for this is that to the human ear, some gong sounds become unpleasant if they persist for too long a time. A high-frequency gong sound should decay or damp out fairly rapidly, but the ear will tolerate a longer persistence of the lower frequencies.) Finally, the metal must be suitable for fabricating a gong that will not have objectionable "beat frequencies"— unpleasant low-frequency pulsations resulting from strains in the material.

Of the six metals and alloys, some had to be ruled out for one or more of the above reasons. Stainless steel gongs, for example, exhibited bad beat frequencies caused by the strains introduced into the metal in the forming process. These strains could not be satisfactorily reduced by annealing. Brass could not be used for high-frequency gongs because of the large thicknesses involved, and aluminum was unsuitable because of unacceptable decay rates.

By the use of silicon-copper, cold rolled steel, and brass, a series of eight distinctive-tone gongs was developed. These are shown in Figure 3, along with their fundamental frequencies. A silicon copper was chosen for the two low-frequency gongs, and cold rolled steel was chosen for the four higher-frequency units. The two standard brass C-type ringer gongs were retained for the intermediate frequencies. These materials have tempers suitable for forming, and annealing reduces beat frequencies to an unobjectionable rate. From Figure 3, it can be seen that by proper combination of these eight gongs into pairs, seven distinctive ringer combinations are achieved, of which one (number 3) is the standard ringer pair used in most 500 sets. Other combinations may be used in special applications.

These gongs have a nominal outside diameter of 1.875 inches and inside height of 0.850 inch. They are formed by cold pressing with a punch and die, and the strains introduced in this cold-working process are subsequently relieved by annealing. The silicon copper and brass gongs are corrosion resistant, but the cold rolled steel gongs are given a light coating of a phosphate rust preventive which does not appreciably affect gong frequency or decay rate.

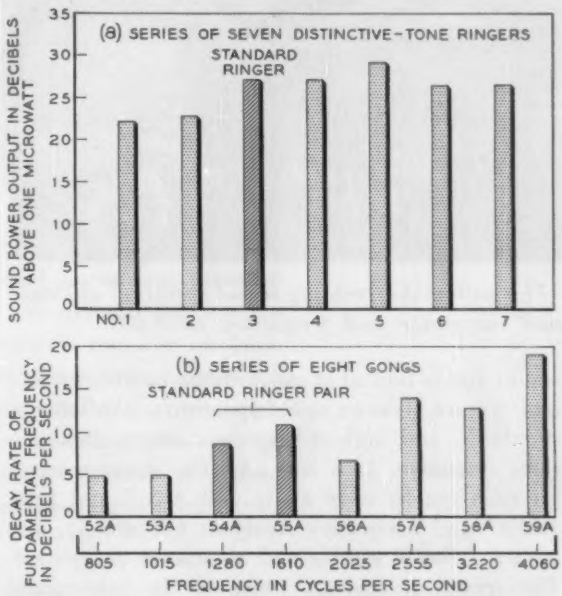


Fig. 5 — (a) Sound-power output in 500 set of the seven distinctive ringers; (b) decay rates of the eight gongs incorporated into the ringers.

When installed in telephone sets, the seven ringer combinations yield the sound-power outputs shown in Figure 5(a). The outputs range from 22 db to 29 db above one microwatt. The decay rates for the fundamental frequencies of the individual gongs are shown in Figure 5(b), where it is noticed that the higher-frequency units generally have the greater decay rate (less persistence). This is a desirable characteristic for pleasantness of

Fig. 6 — The author determining sound spectrum of ringer with sound integrator and frequency analyzer.

sound and is typical of musical instruments in general. Figure 4 shows sound spectra for the lowest-, standard-, and highest-frequency ringer combinations (numbers 1, 3 and 7). The measurements for such graphs were made with the Sound Integrator* and Frequency Analyzer (Figure 6), and with a Level Recorder and associated equipment. The spectrum analyses illustrate the inharmonic relationships of the overtones and the fact that many more overtones are present in the output of the lower-frequency units.

The seven ringer combinations designed in this project provide the desired degree of distinctiveness, but for maximum effectiveness in an actual installation, one must take account of several other factors — the acoustic nature of the room or office in which the 500 sets are placed, the number of telephones in a given area, and the spacing and distribution of the positions. In general, it is desirable to use as wide a frequency separation as conveniently possible for a given number of telephones. However, in any situation, the standard ringer combination is used as widely as feasible.

In the initial tests, observers with deficient hearing were taken into account in determining the effectiveness of the distinctive pitch interval for experimental ringers, but the question remained as to the degree of effectiveness in this circumstance of the actual designs as installed in 500 sets. Accordingly, additional tests were conducted with a number of such observers, two of whom were accustomed to wearing hearing aids. As earlier, the tests were conducted under quiet conditions and in the presence of typical room noise and wide-frequency band noise. These tests indicated that, in general, hard-of-hearing users will find the three ringers of intermediate frequency (numbers 3, 4 and 5) more effective, with number 4 most effective for general room noise. In the presence of considerable high-frequency noise, however, ringer numbers 2 and 3 are to be preferred; and in situations where the hard-of-hearing user is frequently at some distance from his telephone (say 10 to 20 feet), the tests indicate that ringer number 5 will sound louder than others in the series.

These distinctive-tone gongs for the 500 set illustrate the care and close attention that must be paid to designs for use by the telephone customer. In all cases, the convenience and utility to the many users are of major importance along with the strictly technical and scientific aspects of the design. These distinctive ringers should be very helpful to business office procedure.

* Record, *September, 1954, page* 331.

THE AUTHOR

R. T. Jenkins was born in Exeter, Devon, England, and he received the B.S. degree in 1917 and E.E. degree in 1920 from Cooper Union. He joined the Western Electric Company Engineering Department in 1916, where his early work was concerned with telephone transmitter and receiver testing methods and telephone transmission problems. After incorporation of Bell Telephone Laboratories, Mr. Jenkins concentrated on general acoustical measurements in the Research Department, and on the development and calibration of telephone instruments. From 1942-1946 he engaged in work for the N.D.R.C. and the Navy Department. Since 1946, he has specialized in the development of station signals and acoustical methods of measurement of station apparatus components, and at present he is engaged in the field of new coin-telephone exploratory development. Mr. Jenkins is a member of the American Institute of Physics and a charter member of the Acoustical Society of America.

Remote Positions for CAMA

F. N. ROLF
Switching Systems Development II

The centralized automatic message accounting system brings the benefits of direct distance dialing to those areas where local automatic message accounting installations would not be economical. At present this system requires that an operator ask for the calling customer's number on each outgoing call. In many areas, it is desirable to locate the operator positions in a building some distance away from the actual switching equipment. In these installations, provision must be made for signaling between the operator and the equipment without increasing the cost to such an extent that the arrangement becomes uneconomical. Such signaling arrangements have been developed by the Laboratories.

Centralized automatic message accounting (CAMA)* has been developed for crossbar tandem switching offices to extend the dialing range of customers who are served by offices not equipped with local AMA. In addition to crossbar tandem, CAMA will soon be used in No. 5 crossbar offices which handle tandem traffic, and in No. 4A toll crossbar offices.

While the connections for a CAMA call are being made, an operator position is attached to the circuit briefly. The operator determines the calling customer's telephone number and keys it into the CAMA equipment. In most CAMA installations, the operator's switchboard is located in the same building as the switching equipment. In some installations, however, this may not be desirable; there may not be enough space for the switchboard, or it may be too expensive to establish an operating center, with its associated lounge and cafeteria facilities, if there are no other switchboards in the building. It is usually preferable to locate the CAMA position in a building where there are other switchboards to permit more efficient operation by providing a larger pool of operators and common facilities.

The CAMA operator sits at a low cordless switchboard, as shown above. When a call comes in, a supervisory lamp lights and she hears a double "zip-tone" (beep-beep). She then asks the calling customer's number and keys it into the CAMA equipment. Ordinarily, her supervisory lamp signal goes off at this time and she is through with the call. Sometimes, however, she receives a reorder signal —a flashing lamp. This may be because the customer misunderstood and gave the called number, or because the operator inadvertently pressed two keys at once. The operator presses her register-reset (RR) key to stop the flashing signal and erase any calling number digits that have been registered. She then questions the customer again, if necessary, and rekeys. She also uses the RR key to correct any error she detects in keying. If the CAMA operator

* Record, *July*, 1954, *page* 241.

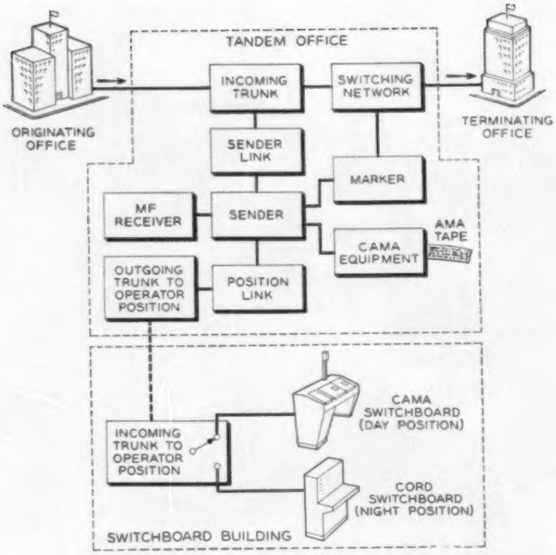


Fig. 1 — Equipment arrangement for remote CAMA operator positions.

is unable to complete the keying operation successfully, she tells the customer to hang up and then dial zero for regular operator assistance. If she cannot free her position in this way, she presses a position-disconnect (PD) key which directs the call to an overflow tone trunk. An interrupted tone notifies the customer to hang up and try again.

When the CAMA switchboard is located in a tandem office, as many wires as are needed to transmit the necessary signals without complicated circuitry can be economically provided from the switchboard keys, lamps and operator's telephone to the tandem office equipment. When the switchboard is miles away from the tandem office equipment, however, it is worth while resorting to more complex arrangements to save outside plant. Two pairs of wires per position are provided between the buildings; one for talking, and one for multifrequency (MF) pulsing from the operator's keyset to the CAMA equipment. This permits the operator to start keying before the customer has finished giving his number, and results in a saving of operator's work time.

As shown in Figure 1, some of the incoming trunks of the remote switchboard are arranged so that they can be transferred to a cord switchboard at night. The operator at such a position handles her cord calls in the usual way, and also handles CAMA calls by using her keyset, just as at the regular CAMA switchboard. The night operator is available for CAMA calls whenever she does not have a TALK key operated. While she is handling a CAMA call, her TALK keys are made ineffective. A situation may arise, however, that requires special treatment: A CAMA call may be directed to a night operator just as she operates one of her TALK keys to answer a cord call. In this case the CAMA call takes precedence. No subsequent CAMA calls can come in, however, until the operator restores her TALK key. Thus a toll call is not kept waiting unduly.

The various signal paths between the crossbar tandem office and the remote CAMA switchboard are indicated in Figure 2. The talking pair provides a connection from the calling customer, through the sender, to the CAMA operator. "Zip" tones from the outgoing trunk are sent over this same pair to the operator. DC signals are also sent over this pair between the incoming trunk and the sender for position disconnect and lamp control. The keying pair carries audio-frequency signals from the ten-button keyset and the register-reset key to the

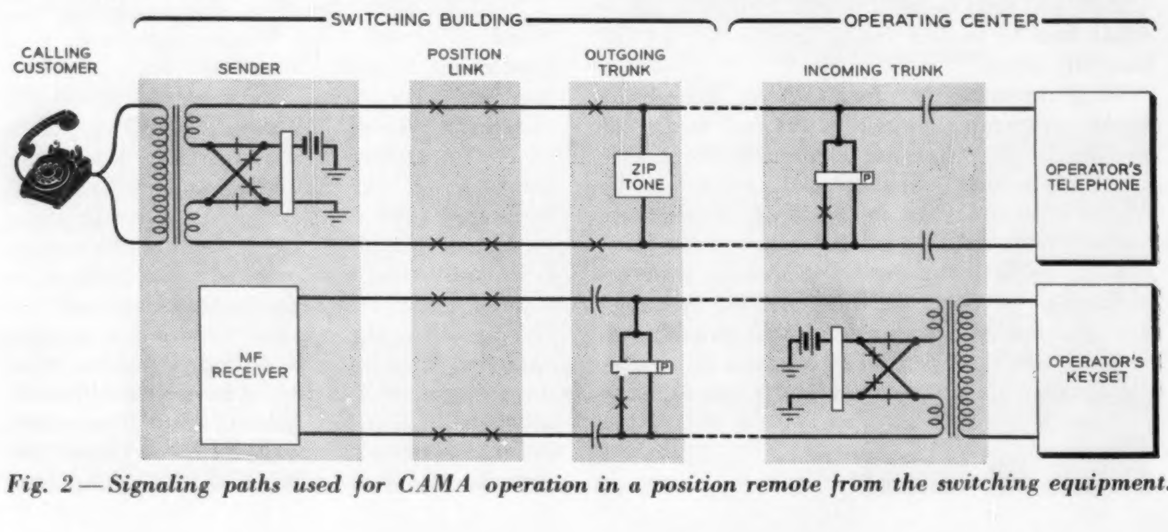


Fig. 2 — Signaling paths used for CAMA operation in a position remote from the switching equipment.

sender, and dc signals between outgoing and incoming trunks to indicate seizure and operator availability.

When an operator is available, the outgoing trunk makes itself available to the position link. When this link connects a sender to the trunk, a "seizure" signal is sent to the incoming trunk over the keying pair. If a night operator has just operated a TALK key, the "seizure" signal disables that key to give precedence to the CAMA call. The incoming trunk places a "not available" signal on the keying pair. When the sender is ready with the calling customer, it sends a "lamp on" signal over the talking pair, and the incoming trunk lights the supervisory lamp. The sender also causes the outgoing trunk to send zip tones to the operator. An "operator present" signal is then returned to the sender.

After keying has been completed, the sender passes the keyed number to the CAMA equipment and receives a signal to release the position. The sender then releases the position link and the outgoing trunk to the position. The incoming trunk receives a "lamp off" signal on the talking pair and a "release" signal on the keying pair, and extinguishes the lamp. If this trunk is connected to a night operator, it also makes her TALK keys effective again. An "available" signal is returned to the outgoing trunk if the operator is free to handle another call.

A reorder signal must be given to the operator if the CAMA equipment rejects the number she keys, as when the customer gives her the called number, for example. To signal "reorder," the sender changes the "lamp on" to the "lamp off" signal. When the incoming trunk receives a "lamp off" signal while the "seizure" signal remains, it flashes the lamp. The operator uses her register reset key to reset the sender, the sender returns the "lamp on" signal, and the incoming trunk changes the supervisory lamp from flashing to steady. If the operator presses her position-disconnect key, the "operator present" signal is withdrawn from the talking pair. This causes the sender to release the position link, freeing the operator's position. The sender then connects the customer to a tone trunk.

When a CAMA switchboard is located at a remote point, the "calls-waiting" signal lamps and

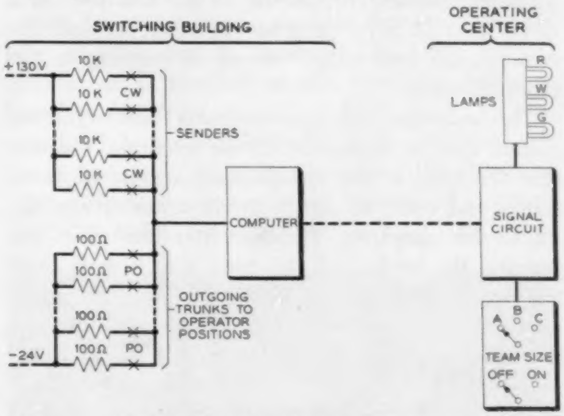


Fig. 3 — "Calls-Waiting" signal equipment.

keys must also be located there. The calls-waiting signal circuit is a simple computer which measures the ratio of senders having calls waiting to occupied CAMA operator positions. This computer controls lamp signals at the switchboard so that the proper number of operators can be assigned to meet changes in the traffic load. If the ratio is low, no lamps are lighted. As it increases, the computer lights green, then green and white, and finally green, white, and red lamps. The computer is controlled by two keys at the switchboard – an ON-OFF key, and a TEAM SIZE key. The latter has three positions, designated A, B and C, and is set to vary the sensitivity of the computer according to the

THE AUTHOR

F. N. ROLF, a native of East Orange, N. J., has been a member of the Switching Development Department since joining Bell Telephone Laboratories in 1937, except during World War II when he was engaged in radar development. At present he is in charge of a group designing circuits for crossbar tandem. His earlier work was on crossbar tandem switching circuits, AMA, and the No. 1 crossbar telephone switching system. Mr. Rolf received a B.S. degree in Engineering from Haverford College in 1935 and a B.S. degree in Electrical Engineering from Massachusetts Institute of Technology in 1937.

number of operators on duty. When the switchboard is located in a separate building from the switching equipment, the computer portion of the calls-waiting signal equipment is kept in the central office building as shown in Figure 3. It is thus necessary to send four signals from the computer to the switchboard – dark (no lamps), green, white and red, and four signals from the switchboard to the computer – team sizes A, B and C, and off. A signaling method developed to do this job on a single pair of wires uses MF signaling toward the switchboard and simple on-off dc signals in the other direction.

The operation of the computer and signaling system can be explained by an example. Assume that the keys at the switchboard are set to TEAM SIZE A and ON. The signal circuit sends an ON signal to the computer. The computer must then determine the setting of the team size key. It does this by sending the B – MF signal. This, in effect, asks first "Is it team size B?" If the computer does not receive an answer within a short time, it removes the B signal and sends out A, to ask "Is it A?" If it still does not receive an answer, it asks "Is it C?"* In the case being considered, the signal circuit answers "Yes" to the team size A question by sending an OFF signal. The computer removes the MF signal and the signal circuit restores its ON signal. Then the computer sends the appropriate lamp signal and the signal circuit lights the corresponding lamps and acknowledges with an OFF signal. Following this the computer removes the MF signal and the signal circuit returns to the ON signal. Whenever a change in the "calls-waiting" ratio requires it, the computer sends a new lamp signal which is acknowledged in the same way.

Suppose now the TEAM SIZE key is moved to B. The signal circuit sends an OFF signal. The computer takes this at its face value and starts to turn itself off. Whenever it does so, however, it always sends a "good night" MF signal for a measured interval. If the system had really been turned off, the signal circuit would be released and would not notice the "good night." In the assumed case, the TEAM SIZE key was moved but the ON-OFF key is still ON, and the "good night" signal causes the signal circuit to respond with an ON signal. To the computer, which has released, this looks as though it were just being turned on. It therefore starts the question and answer game again to determine the team size setting, and then sends the appropriate lamp signals.

* The question order B, A, C rather than A, B, C was chosen because it fits better with the previously designed computer.

Teletype Corporation Celebrates 50th Anniversary

In 1907 the Morkrum (Morton and Krum) Company began producing the first practical teleprinters, and in 1915 the company's business increased greatly when the Associated Press decided upon the Morkrum machine for fast distribution of news. In 1925 the name of the machine was changed to "Teletype," a registered trademark, and in 1928 the company name was officially changed to the Teletype Corporation. The company, now a subsidiary of the Western Electric Company, joined the Bell System in 1930. This is part of the story of the organization, celebrating its 50th anniversary on October 7, which has produced 260,000 teletypewriters now in use throughout the world.

In the Teletype Corporation's Chicago plant, employees assemble teleprinter equipment.

Through fifty years of research and development, the crude machines of 1907 have evolved into modern, versatile equipment operating at 60 to 100 words per minute. A special military application uses a system that transmits 600 words per minute, and Bell Laboratories and Teletype engineers are doing experimental work at even higher speeds.

As an indication of the important present and future role of the teletypewriter in communications, the Teletype Corporation produced 75,000 machines in 1956 and expects to ship about the same number this year. Because of their versatility, speed, and high degree of automatic operation, teletypewriters are incorporated into systems of business-office and industry automation and into systems of integrated data processing, a field in which the Laboratories is engaging in extensive planning and development.

G. N. THAYER

H. R. HUNTLEY

G. N. Thayer and H. R. Huntley in New Positions

The American Telephone and Telegraph Co. announced the appointment of Harold R. Huntley as Chief Engineer, effective August 1st. He succeeds Gordon N. Thayer, who was elected Vice President of the Ohio Bell Telephone Company. Mr. Thayer is a former Vice President of Bell Telephone Laboratories.

Mr. Thayer succeeds W. S. Sparling, former Vice President of Ohio Bell who has been named President. J. A. Greene, former Ohio Bell President, has been named Chairman of the Board of Directors.

Mr. Huntley has been Director of the Customer Products Planning Division of A. T. & T. He began his telephone career in 1917 as a transmission technician for the Wisconsin Telephone Company. He joined the Operation and Engineering Department of A. T. & T. in 1930. Since then he has held various engineering positions on the A. T. & T. staff.

Mr. Huntley is a graduate of the University of Wisconsin. He is a fellow of the A.I.E.E., a senior member of the I.R.E., and a member of the Montclair Engineering Society and Eta Kappa Nu.

Mr. Thayer, who was born in Delta, Colo., is a graduate of Stevens Institute of Technology. He began his career as a member of the technical staff of Bell Laboratories in 1930. For ten years his special interest was the development of mobile radio communication equipment and systems. In 1940, Mr. Thayer began work on radar systems, and, later, microwave radio relay systems.

In 1949 he became concerned with the development of communications systems, including the transcontinental radio relay system, the Key West-Havana submarine cable system, and overseas radio projects. He was appointed Assistant Director of Transmission Systems Development in 1949 and Director of Transmission Development in 1951.

Mr. Thayer was named a Vice President of the Laboratories in charge of its military development program in 1952, and a year later became Vice President in charge of Switching and Transmission Development. He was appointed Chief Engineer for A. T. & T. in 1955. He is a fellow of the I.R.E., a member of the A.I.E.E., and a member of the Army Scientific Advisory Panel.

Dr. M. J. Kelly Receives Air Force Exceptional Service Award

Dr. M. J. Kelly received the Exceptional Service Award from the Department of the Air Force on July 19. The award, honoring Dr. Kelly for his services as a member of the Scientific Advisory Board to the Chief of Staff of the U. S. A. F., was presented in ceremonies held in the office of Air Force Secretary James H. Douglas in Washington.

The citation accompanying the award declares that Dr. Kelly "distinguished himself by exceptionally meritorious service to the Department of the Air Force as a member of the Scientific Advisory Board to the Chief of Staff from June 1950 through January 1957. He served as Vice Chairman of the Board from the time of his initial appointment in 1950 through 1954, and as Board Chairman during 1955. Dr. Kelly's leadership in Board affairs and his personal contributions," the citation continues, "materially enhanced the application of scientific advances to air weapon systems and the development of United States Air Power during this critical period. The singularly distinguished accomplishments of Dr. Kelly have earned him the gratitude of the United States Air Force."

Dr. M. J. Kelly (right) accepts Exceptional Service Award of the Air Force from Air Force Secretary James H. Douglas.

Dr. Kelly in Bureau of Standards and Atoms for Peace Posts

Dr. M. J. Kelly has accepted an invitation from Secretary of Commerce Sinclair Weeks to serve for another five-year term on the Statutory Visiting Committee of the National Bureau of Standards. A member of the committee since 1952, he has served as chairman since 1954.

Dr. Kelly has also been elected a trustee and member of the corporation of Atoms for Peace Awards, Inc. He has served as a member of the organization and planning committee for the awards since 1955. The Atoms for Peace Awards were established by the Ford Motor Company Fund in 1955 to provide incentive for the world's scientists, inventors and engineers to find new ways in which atomic energy science can be used for the welfare of mankind.

Achievement Award Presented to Walter H. Brattain

W. H. Brattain, member of the Physical Research Department at Bell Laboratories and co-winner of the 1956 Nobel Prize for Physics, received the 1956 Appreciation of Achievement award from the Chamber of Commerce of Walla Walla, Washington, on August 6. The award cited Mr. Brattain for "his outstanding contribution to the field of electronics, and his selection as a 1956 Nobel Prize winner, which have brought recognition and pride to Walla Walla and Whitman College."

On the occasion of the award, Mr. Brattain announced a plan to establish a professorship at Whitman College in honor of the late Prof. Benjamin H. Brown. H. E. Mendenhall and Mr. Brattain are co-chairmen of a committee set up, with the approval of the Whitman College board of trustees, to raise the funds for the professorship.

Acoustical Society of America Honors Dr. Harvey Fletcher

Dr. Harvey Fletcher, former Director of Physical Research at Bell Laboratories and now head of the Physics Department at Brigham Young University, has been awarded the Gold Medal of the Acoustical Society of America. The medal, awarded every two years, was conferred on Dr. Fletcher for his "distinguished contribution to the Society and to the science of acoustics." He was first president of the Acoustical Society and is the third recipient of the award.

Dr. Fletcher began his Bell System career in 1916. He has specialized in the fields of measurement of audition, loudness of complex sounds, the theory of hearing, and the physical nature and transmission of speech and music. For his contributions to science, he was awarded the Levy Gold Medal of the Franklin Institute in 1924 and has also been awarded several honorary degrees. Dr. Fletcher retired from the Laboratories in 1949.

Laboratories Plans New Branch at W. E. Co. in Columbus, Ohio

Bell Telephone Laboratories will establish a branch laboratory at the new Western Electric plant being constructed in Columbus, Ohio. This plant, which will cost 50 million dollars, is expected to be available for initial occupancy in the middle of 1959.

The Columbus plant will be a Western Electric center for production of crossbar equipment and will also be the engineering headquarters for both crossbar and electronic switching equipment.

This branch laboratory, like those already in operation, will extend the Laboratories' ability to discharge its development and design responsibilities and further strengthen the development-design-manufacture bonds between the Laboratories and Western Electric.

K. G. Compton and A. Mendizza Receive ASTM Award

The American Society for Testing Materials has presented its Sam Tour Award to K. G. Compton and A. Mendizza of the Chemical Research Department at Bell Laboratories, co-authors of a paper entitled "Galvanic Couple Corrosion Studies by Means of the Threaded Bolt and Wire Test." Presentation was made during the sixtieth annual meeting of the Society in Atlantic City, N. J., on June 19.

The Sam Tour award was established to stimulate research on corrosion testing and testing methods, to encourage presentation to the ASTM of papers on these subjects, and to recognize meritorious efforts in this field. The award-winning paper was delivered at an ASTM symposium in 1955 and was published in the ASTM Special Technical Publication No. 175.

Patents Issued to Members of Bell Telephone Laboratories During June

Abbott, H. H., and Welch, P. V. – *Station Identification Systems* – 2,794,859.

Bennett, W. R. – *Multiple Quantized Feedback in a Regenerative Repeater* – 2,797,340.

Black, D. M., and Hoffman, H. H. – *Amplifiers Having Mismatched Interstage Networks* – 2,794,865.

Clogston, A. M. – *Electrical Conductor Comprising Multiplicity of Insulated Filaments* – 2,797,392.

Clogston, A. M. – *Composite Wave Guide* – 2,797,393.

Clogston, A. M. – *Electrical Conductor Having Composite Central Dielectric Member* – 2,797,394.

Cutler, C. C. – *Frequency Swept Pulse Generator* – 2,795,698.

Ebers, J. J., and Kleimack, J. J. – *Semiconductive Devices* – 2,796,563.

Eglin, J. M. – *Demodulation of Vestigial Sideband Signals* – 2,797,314.

Eigler, J. H., and Sullivan, M. V. – *Method of Treating the Surface of Solids with Liquids* – 2,797,193.

Fletcher, R. C., and Millman, S. – *Magnetrons* – 2,797,362.

Fox, A. G. – *Directional Coupler for All-Dielectric Waveguide* – 2,794,959.

Fuller, C. S. – *Fabrication of Semiconductor Devices* – 2,794,846.

Glass, M. S. – *Magnetrons* – 2,797,361.

Hoffman, H. H., see Black, D. M.

Holden, W. H. T. – *Cold Cathode Tube Circuit* – 2,797,368.

Kircher, R. J. – *Semiconductor Signal Translating Devices* – 2,795,744.

Kleimack, J. J., see Ebers, J. J.

Kock, W. E. – *Directional Transducer* – 2,796,467.

Mallina, R. F. – *Motor Control for Contact Adjusting Machine* – 2,797,377.

Mallinckrodt, C. O. – *Composite Conductors* – 2,796,463.

Mason, W. P. – *Dielectric Amplifier Employing Ferroelectric Materials* – 2,795,648.

Millman, S., see Fletcher, R. C.

Molnar, J. P., and Moster, C. R. – *Traveling Wave Type Electron Discharge Devices* – 2,797,353.

Moster, C. R., see Molnar, J. P.

Oliver, B. M. – *Pulse Operated Circuit* – 2,794,978.

Pfann, W. G. – *Semiconductive Translating Devices Utilizing Selected Natural Grain Bounderies* – 2,795,742.

Reenstra, W. A. – *Line Circuit* – 2,796,465.

Shockley, W. – *Nonreciprocal Circuits Employing Negative Resistance Elements* – 2,794,864.

Shockley, W. – *High Frequency Negative Resistance Device* – 2,794,917.

Smith, J. L. – *Low Voltage Percussion Welder with Auxiliary Arc Striking Circuit* – 2,797,302.

Sullivan, M. V., see Eigler, J. H.

Tillotson, L. C. – *Microwave Filters* – 2,795,763.

Van Roosbroeck, W. W. – *Semiconductor Translating Device and Circuit* – 2,794,863.

Welch, P. V., see Abbot, H. H.

Yostpille, J. J. – *Identification of Serial Stored Information* – 2,794,970.

Papers Published by Members of the Laboratories

Following is a list of the authors, titles and places of publication of recent papers published by members of the Laboratories:

Benson, K. E., see Pfann, W. G.

Benson, K. E., see Wernick, J. H.

Birdsall, H. A., *Insulating Films*, in "Digest of Literature on Dielectrics" (Publication 503, National Academy of Sciences, National Research Council), **19-1955**, pp. 209-220, June, 1957.

Bogert, B. P., *Response of an Electrical Model of the Cochlear Partition with Different Potentials of Excitation*, J. Acous. Soc. Am., **29**, pp. 789-792, July, 1957.

Boyet, H., see Weisbaum, S.

Brady, G. W., *Structure of Tellurium Oxide Glass*, J. Chem. Phys., **27**, pp. 300-303, July, 1957.

Brady, G. W., and Krause, J. T., *Structure in Ionic Solutions. I*, J. Chem. Phys., **27**, pp. 304-308, July, 1957.

Frisch, H. L., *Time Lag in Nucleation*, J. Chem. Phys., **27**, pp. 90-94, July, 1957.

Fuller, C. S., and Reiss, H., *Solubility of Lithium in Silicon*, J. Chem. Phys., Letter to the Editor, **27**, pp. 318-319, July, 1957.

Gibbons, D. F., *Acoustic Relaxations in Ferrite Single Crystals*, J. Appl. Phys., **28**, pp. 810-814, July, 1957.

Githens, J. A., *The Tradic Leprechaun Computer*, Proc. Eastern Joint Computer Conference, A.I.E.E. Special Publication, **T-92**, pp. 29-33, Dec. 10-12, 1956.

Kiernan, W. J., *Appearance Specifications and Control Methods*, Elec. Manufacturing, **60**, pp. 126-129, 294, 296, 298, July, 1957.

Krause, J. T., see Brady, G. W.

Logan, R. A., and Peters, A. J., *Diffusion of Oxygen in Silicon*, J. Appl. Phys., Letter to the Editor, **28**, pp. 819-820, July, 1957.

Luke, C. L., *Determination of Sulfur in Nickel by the Evolution Method*, Anal. Chem., **29**, pp. 1227-1228, Aug., 1957.

Mertz, P., *Information Theory Impact on Modern Communications*, Elec. Engg., **76**, pp. 659-664, Aug., 1957.

Nielsen, E. G., *Behavior of Noise Figure in Junction Transistors*, Proc. I.R.E., **45**, pp. 957-963, July, 1957.

Papers Published by Members of the Laboratories, Continued

Perry, A. D., Jr., *Pulse-Forming Networks Approximating Equal-Ripple Flat-Top Step Response*, I.R.E. Convention Record, **2**, pp. 148-153, July, 1957.

Peters, A. J., see Logan, R. A.

Pfann, W. G., and Vogel, F. L., Jr., *Observations on the Dislocation Structure of Germanium Crystals*, Acta Met., **5**, pp. 377-384, July, 1957.

Pfann, W. G., Benson, K. E., and Wernick, J. H., *Some Aspects of Peltier Heating at Liquid-Solid Interfaces in Germanium*, J. Electronics, **2**, pp. 597-608, May, 1957.

Pfann, W. G. *Zone Melting*, Metallurgical Reviews (London), **2**, pp. 29-76, May, 1957.

Reiss, H., see Fuller, C. S.

Turrell, G. C., Jones, W. D., and Maki, A., *Infrared Spectra and Force Constants of Cyanoacetylene*, J. Chem. Phys., **26**, pp. 1544-1548, June, 1957.

Van Bergeijk, W. A. M. *The Lung Volume of Amphibian Tadpoles*, Science, **126**, p. 120, July, 19, 1957.

Vogel, F. L., Jr., see Pfann, W. G.

Weisbaum, S., and Boyet, H., *Field Displacement Isolators at 4-, 6-, 11-, and 24-Kmc*, Trans. I.R.E. PGMTT, **MTT-5**, pp. 194-198, July, 1957.

Weiss, M. T., *Quantum Derivation of Energy Relations Analogous to Those for Nonlinear Reactances*, Proc. I.R.E., Letter to the Editor, **45**, pp. 1012-1013, July, 1957.

Wernick, J. H., and Benson, K. E., *Zone Refining of Bismuth*, J. Metals, **9**, p. 996, July, 1957.

Wernick, J. H., see Pfann, W. G.

Talks by Members of the Laboratories

During July a number of Laboratories people gave talks before professional and educational groups. Following is a list of speakers, titles, and places of presentation.

I.R.E.-A.I.E.E. Semiconductor Device Research Conference, Boulder, Colorado

Anderson, O. L., see Christensen, H.

Andreatch, P., Jr., see Christensen, H.

Backenstoss, G., *Control of Lifetime Sensitive Device Characteristics by Electron Bombardment.*

Bakanowski, A. E., Cranna, N. G., and Uhlir, A., Jr., *Diffused Germanium and Silicon Nonlinear Capacitor Diodes.*

Baker, A. N., and Bemski, G., *Vacuum Heat Treatment.*

Batdorf, R. L., *An Application of Vacuum Diffused Silicon To Transistor Fabrication.*

Bemski, G., see Baker, A. N.

Christensen, H., Anderson, O. L., and Andreatch, P., Jr., *A New Technique for Bonding Metals to Silicon and Germanium and Its Application to Device Technology.*

Cranna, N. G., see Bakanowski, A. E.

Hines, M. E., *Amplification In Nonlinear Reactance Modulators*, (Presented by Bakanowski, A. E.)

Mackintosh, I. M., *Three Terminal PNPN Transistor Switches.*

Moll, J. L., see Senitzky, B.

Senitzky, B., and Moll, J. L., *Breakdown in Silicon at High Frequencies.*

Uhlir, A., Jr., *Shot Noise in Amplifying Frequency Converters.*

Uhlir, A., Jr., see Bakanowski, A. E.

Wahl, A. J., *An Analysis of Transistor Base Spreading Resistance and Associated Effects.*

International Congress of Crystallography, Montreal, Canada

Bond, W. L., *Absorption, Lorentz and Double Polarization Corrections for the Equi-inclination Weisenberg.*

Bond, W. L., *Dislocations in Silicon.*

Geller, S., and Gilleo, M. A., *The Crystal Structure and Ferrimagnetism of Yttrium-Iron Garnet, $Y_3Fe_2(FeO_4)_3$.*

Gilleo, M. A., see Geller, S.

Prince, E., *Neutron Diffraction Measurements on Yttrium-Iron and Yttrium-Aluminum Garnets.*

Gordon Conferences, New Hampshire

Brown, W. L., *The Interaction of a Semiconductor with Its Surface.*

Garrett, C.G.B., *Semiconductors in Organic and Inorganic Chemistry.*

Snoke, L. R., *Evaluating the Resistance of Organic Materials to the Marine Environment.*

Wilk, M. B., *Choosing Proper Mathematical Models.*

Other Talks

Bavelas, A., *What Gets Communicated?*, Silver Bay Conference on Human Relations in Industry, Lake George, N. Y.

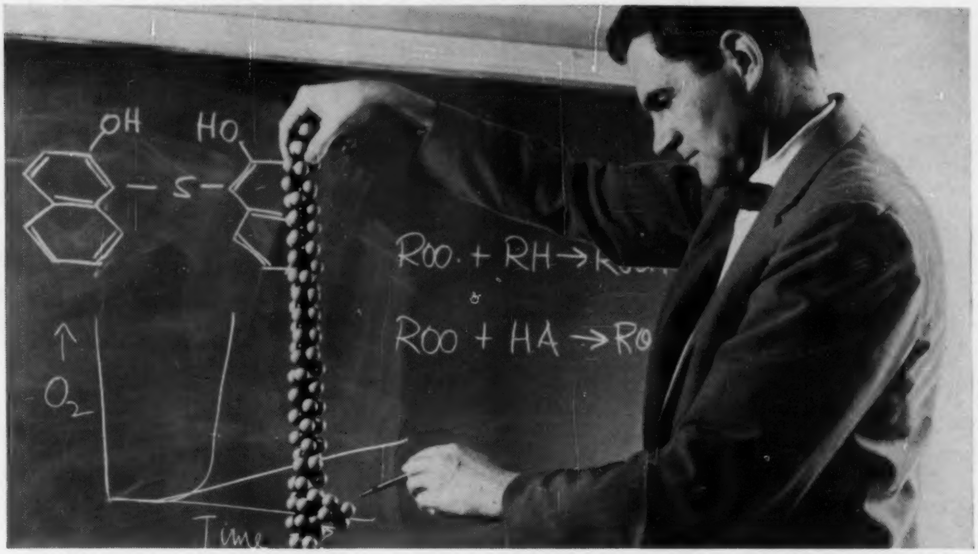
Becker, J. A., *Some Aspects of the Physics and Chemistry of Metal Surfaces as Revealed by New Techniques.* Chemistry Department, University of St. Louis, Mo.

Bommel, H. E., *Ultrasonic Measurements in Normal and Super-conducting Metals*, University of Cologne, Cologne, Germany; Institute of Technology, Stuttgart, Germany; and University of Neuchatel, Neuchatel, Switzerland.

Bowers, K. D., *Masers*, Journal Club, University of Washington, Seattle, Washington.

Deutsch, M., *A Theoretical and Experimental Investigation of Social Emotions*, 15th International Congress of Psychology, Brussels, Belgium.

Graham, R. E., *Communication Theory Applied to Television Coding*, International Symposium of Union of Pure and Applied Physics on Physical Problems of Color Television, Paris, France.



Bell Laboratories chemist Field H. Winslow, Ph.D., Cornell University, with a scale model of a small section of a polyethylene molecule. Branch formation indicated by pencil is vulnerable to oxidation. Dr. Winslow and his associates worked out a simple way to protect long polyethylene molecules needed for durable cable sheathing.

THE DILEMMA OF GIANT MOLECULES
Solution: 2 plus 2 equals 5

Polyethylene is used to protect thousands of miles of telephone cables. It is tough, light and long lasting. Its strength lies in its giant molecules—a thousand times bigger, for example, than those of its brittle chemical cousin, paraffin wax.

But polyethylene has a powerful enemy: oxidation, energized by light and heat, shatters its huge molecules to pieces. This enemy had to be conquered if polyethylene was to meet the rigorous demands of cable sheathing. Paradoxically, it was done by making the whole better than the sum of its parts—just as though 2 plus 2 could be made to add up to 5.

To check the ravages of light, Bell Laboratories chemists devised the simple yet highly effective remedy of adding a tiny dose of carbon black. Then antioxidants, such as those commonly used to protect rubber, were added to check attack by heat. But here the chemists encountered a dilemma: although the carbon black protected against the effects of light, it critically weakened the effectiveness of the antioxidants.

To solve this dilemma, Bell Labs chemists developed entirely new types of antioxidants—compounds not weakened by carbon black but which, intriguingly, are very much more effective when carbon black is present. The new antioxidants, plus carbon black, in partnership, provide long-lasting cable sheath—another example of how research at Bell Telephone Laboratories works to improve telephone service.

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